Investigation into low cost housing water use patterns and peak factors

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Declaration

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Abstract

A need was identified to gain new insight and knowledge regarding the water demand of low cost housing (LCH) developments. More specifically, the primary objective of this study was to improve water demand guidelines for LCH projects through developing a novel water demand pattern. Peaking factors were also established from field data.

For the purposes of this study, the recorded water consumption data from 20 houses in Kleinmond, a town in the Western Cape Province of South Africa, was used. The data was sorted, filtered, and finally adapted where necessary. The prepared data was used to develop a water demand pattern for each house considered, from which an average diurnal water use pattern was developed. In addition, an average diurnal water use pattern for a weekday and a weekend day, as well as seasonal summer and winter water use patterns, were developed and compared.

Peaking factors were also calculated using the processed data. Similar to previous studies, peaking factor guidelines were developed in terms of the number of consumers. Three peaking factors, namely peak 15-minute factors, peak hourly factors and peak daily factors, were calculated.

The water use pattern derived from the data compared well with the results of previous studies for high-income areas, with two distinct peaks. However, the resulting diurnal water use pattern is notably different when compared to the earlier reported patterns for LCH.

The calculated peaking factors resulted in different ranges of peaking factor values according to the time intervals of the readings. A relationship was found between the magnitude of the peaking factors and the length of the peak factor interval. Peaking factors were also closely related to the number of households concerned. As the number of households increased, the peaking factor values decreased, in line with earlier reports.

The study provided an updated diurnal water use pattern for LCH areas with mainly working occupants. Furthermore, the weekend morning peak was found to occur later than the weekday morning peak, while the summer and winter water use patterns were found to be similar. The peaking factors calculated were 65% higher, in comparison to those in the previously developed guidelines. The water use pattern for LCH and the corresponding peaking factors presented in this thesis could be used in future for water demand modelling and time simulations in LCH areas with predominantly working occupants.

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Abbreviations and acronyms

ACLUMP	Australian Collaborative Land Use and Management Program
AADD	Average Annual Daily Demand
ADD	Average Daily Demand
CSIR	Council of Scientific and Industrial Research
DHS	Department of Human Settlements
ee	equivalent erven
EPS	Extended Period Simulation
GSM	Global System for Mobile Communication
LCH	Low Cost Housing
M	Water Meter
MNF	Minimum Night Flow
PDF	Peak Day Factor
PF	Peaking Factor
$PF_{15\text{-}min}$	Peak 15-minute Factor
PHF	Peak Hour Factor
PPH	People Per Household
RTU	Remote Terminal Units
SA	South Africa
SPLUMB	Australian Spatial Planning and Land Use Management Bill
SSS	Steady State Simulation

1. Introduction

1.1 Background

The newly elected democratic government in South Africa in 1994 committed itself to reducing the housing shortage in South Africa. In order to achieve this, the government has established a number of social housing institutions. While the supply of social housing is increasing, demand for these houses is increasing as well, and at an even faster rate (Ngxubaza, 2010).

The continuous urban development of South Africa forces continuous development of the infrastructure and water services. This phenomenon has highlighted the need for accurate planning and design by municipalities to satisfy water demand. A need for improved planning requires improvement in water demand estimation because of the significant influence water demand estimates have on the municipal water and sewer infrastructure (Van Zyl *et al.,* 2008:381).

In order to achieve improved planning, municipal engineers and engineering consultants require accurate and reliable data, design guidelines for estimating water demand, as well as an indication of the factors influencing water demand. In response to these requirements, this study was initiated to determine water demand patterns for LCH units and to derive related peaking factors.

1.2 Problem definition

Infrastructural development and the concomitant need for more potable water services due to the expansion of urban areas, has highlighted the importance of accurate water demand estimates in planning and designing municipal water services. These water demand estimates are used to calculate peak water demands as well as sewer flow, from which the necessary infrastructural requirements can be determined (Van Zyl *et al.,* 2008:381). Inadequate estimates will lead to a deficiency in basic design information, that could lead to inadequate service provision or water distribution (Van Zyl *et al.*, 2007). The estimation of present water demand, as well as the prediction of future water demand is therefore one of the key inputs in municipal water services planning and design (Van Zyl *et al.,* 2008:381).

City of Johannesburg (1989) first recognised that residential water demand estimates should preferably be based on actual water consumption. However, information on actual water consumption recorded in intervals of less than an hour, especially on LCH units, is not readily available.

1.3 Study objective

The main objective of this study was to derive diurnal water use patterns and peaking factors for LCH units. The key objectives of this study were to:

- do a literature study to investigate factors influencing residential water demand, building of a typical 24-hour water use pattern from actual water use data, and the derivation of peaking factors from these patterns.
- obtain data to conduct empirical analyses.
- determine the diurnal water use pattern for a typical LCH unit.
- assess the variations between weekday and weekend diurnal water use patterns, as well as diurnal summer and winter water use patterns.
- explore possible reasons for variations in water use.
- derive peaking factors from water use patterns.

1.4 Restraints

As the purposes of this study were to build diurnal patterns and derive peaking factors for LCH units, recorded data records for this type of residential houses were essential. As far as it is known, the recorded water use of the LCH units in the Western Cape town of Kleinmond was the only record of a LCH suburb in South Africa that had been recorded in smaller intervals than 1 hour. Existing data sets of daily and monthly water readings on LCH units are therefore insufficient for the development of diurnal water use patterns. The recorded water use readings of 20 LCH units at 15-minute intervals were available for the period 28 September 2012 to 16 February 2016, adding up to a total of more than 1.5 million data points.

1.5 Motivation

Accurate and up-to-date data on water demand is essential to ensure that the future water supply reflects current patterns and is designed efficiently from both an engineering and an economic perspective. Understanding residential water use patterns and their corresponding peaking factors is, therefore, critical in determining the pipe infrastructure that would be sufficient to deliver water during peak demand periods.

1.6 Definition of terms

Average Annual Daily Demand

The average annual daily demand (AADD) is the total volume of water delivered to the system in a year expressed as an average value in litres per day. It is therefore likely that each calendar year would have a unique AADD value.

Average Daily Demand

The average daily demand (ADD) is the volume of water delivered to the system in a day, measured between 00:00 and 23:59. The ADD is expressed in litres per day. It is therefore likely that each day would have a unique ADD value.

Diurnal Pattern

The water use cycle over a 24-hour period is termed the diurnal pattern.

Peaking Factor

The definition for a peaking factor (PF) was adopted from Scheepers (2012). A PF is the ratio between the maximum water flow rate during a relatively short time period, say δt, and the average water flow rate during an extended observed period. The peak flow represents the period when maximum, or relatively high, flow rate occurs. In some cases, the AADD is used for the extended period.

2. Literature review

2.1 Low cost housing

The term 'low cost housing' as used in this thesis is also referred to as 'gap housing' and 'social housing' in other sources. The term RDP-housing was also used in the period following the election of the ANC-government in 1994. 'RDP housing' was a central theme of the government's so-called reconstruction and development programme, or RDP (African National Congress, 1994). 'Gap housing' is defined as 'Housing for people whose combined monthly household income is less than R 3 500 per month' (Jacobs *et al.*, 2013). Also, 'social housing', which is very similar to low-income housing, can be defined as 'A rental or co-operative housing option for low- to medium income households (earning no less than R 3500 per month per household) which requires institutionalised management (provided by social housing institutions or other delivery agents) in approved projects in designated restructuring zones with the benefit of public funding' (Le Roux, 2011).

In order to reduce the shortage of houses in South Africa, the Department of Human Settlements (DHS) has created a number of bodies to assist the government. While the supply of LCH units is increasing, the demand for these LCH units is rising at an even higher rate (Ngxubaza, 2010).

2.2 Water demand and demand modeling

2.2.1 Water demand management

Water is a limited resource and the need to efficiently manage its demand and consumption is increasingly gaining recognition (Saleem, 2012:6). With South Africa being an economically developing and water scarce country, water demand management has become a fundamental priority for both water supply companies and public administrations (Van Zyl *et al.*, 2006).

Residential water demand management helps in reducing water deficits, improves the reliability of water supplies, and may reduce the necessity for the construction of large infrastructure and thus the stress imposed on the natural environment. Another benefit of residential water demand management is that it will improve utility management and decrease economic costs, as a result of more efficient, optimum designs.

In summary, water demand management contributes in the following four areas: 1) the reduction in operation and maintenance costs; 2) the downsizing of infrastructure; 3) the decrease in purchase prices for water authorities, and consequently for residents; and 4) extending the lifespan of raw water resources.

Residential water demand management requires a deep understanding of the behaviour of the user in relation to the consumption. The characteristics and trends of residential water demand provide a strong basis for evaluating a range of water demand management strategies and should therefore represent a basic axis of public and private companies' water strategies (Corbella and Pujol, 2009:299).

Water demand estimates are used to calculate peak water demand and sewer flow. Peak flows are then used to determine infrastructural requirements, from which water authorities` budget and capital investment needs are determined.

Water distribution network planning is typically based on the traditional forecast of the water demand of the receiving supply zone. Water demand can vary considerably between water supply zones according to climate, seasonal demand distribution and geographic and topographical features (as discussed in §2.3 – Factors affecting water demand). Estimation of water demand is typically based on long-term consumption records for similar consumer groups and the relevant water agency`s records on network demands. The water network planner also takes the water usage into account according to the type of consumer and the typical diurnal water use patterns (Lucas *et al.*, 2009:1082). The design of water infrastructure requires the selection of a suitable PF for the estimation of design flows. The PF criteria used to design water supply infrastructure are determined from these typical consumer type water use patterns.

2.2.2 Water use in South Africa

The schematic illustrated in Figure 2.1 shows a typical residential unit being supplied with water from a water meter (M). Residential water use can be divided into indoor and outdoor water use, and can be further refined to include the end-uses for each of these water use types.

The use of water is largely dependent on the type of consumer. DWAF (2004) estimated average water use based on information from Rand Water, Durban Water and Waste and Cape Town City Council. The results are presented in Figure 2.2 and show that 50% of the water used in South Africa was for residential (gardening and household), which is the type of consumer with the highest consumption in South Africa. In a similar investigation of water consumption of users in Cape Town by Jacobs *et al.* (2007), the residential fraction of the total water used was reported to be 55%. Figure 2.3 shows end-use information which was estimated by Jacobs *et al.* (2006) without implemented water restrictions. The results were based on actual measurements from 160 residential properties in Cape Town. The toilet, washing machine and bath-shower combined represent the largest indoor end-uses, contributing an estimated 75% of the total indoor demand.

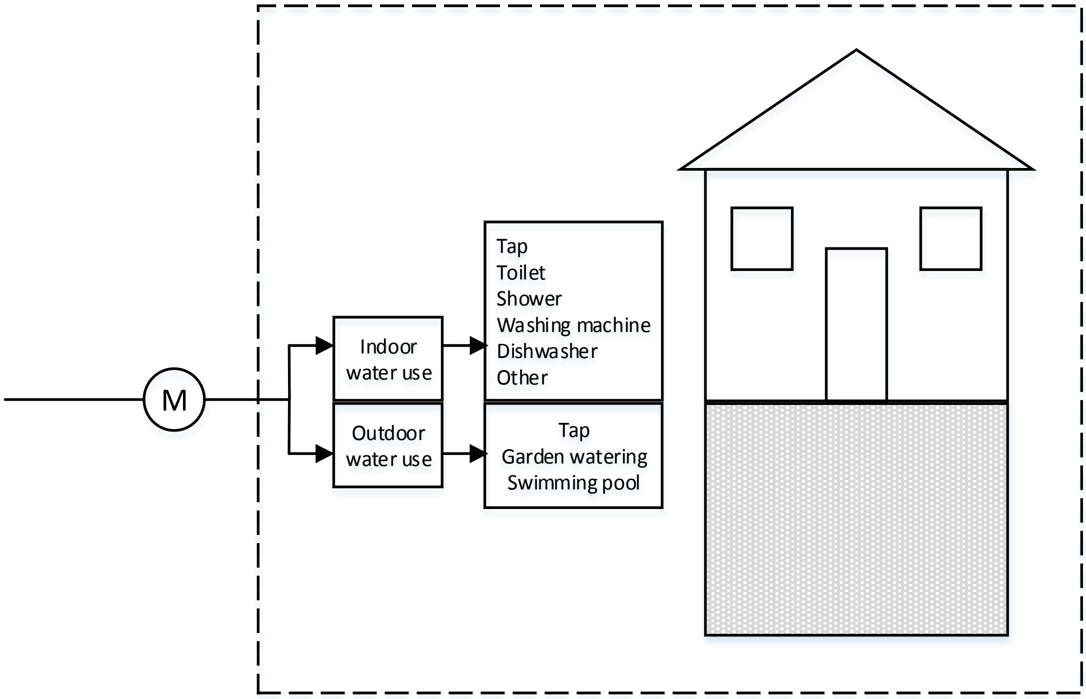

Figure 2.1: Schematic presentation of a residential property and water meter (M)

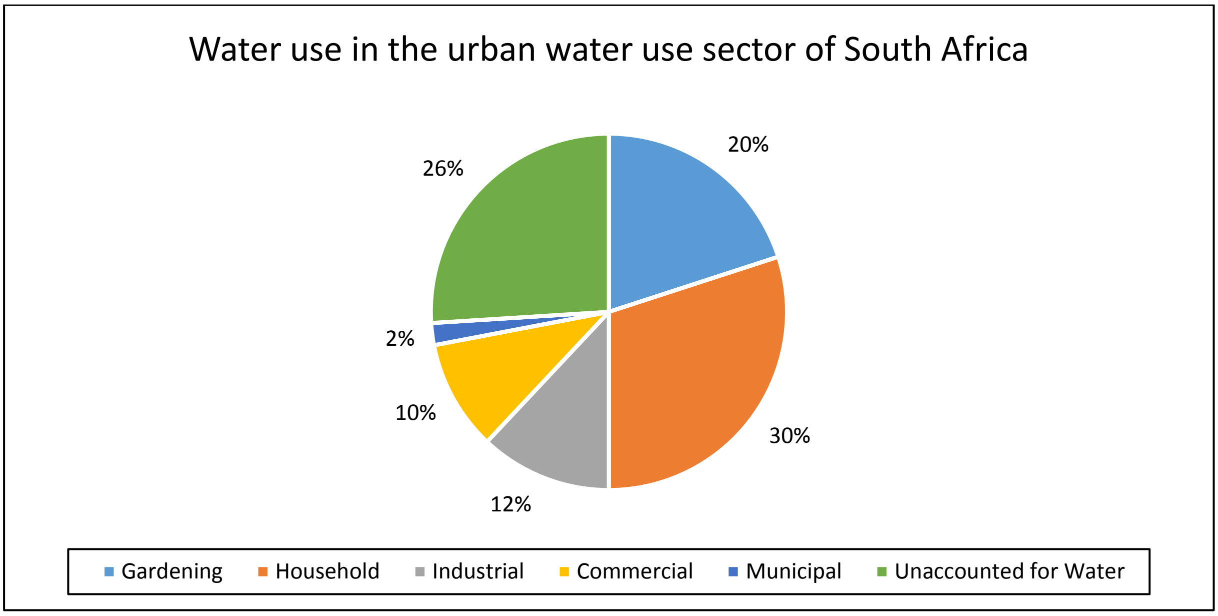

Figure 2.2: Water use in the urban water use sector of South Africa (DWAF, 2004)

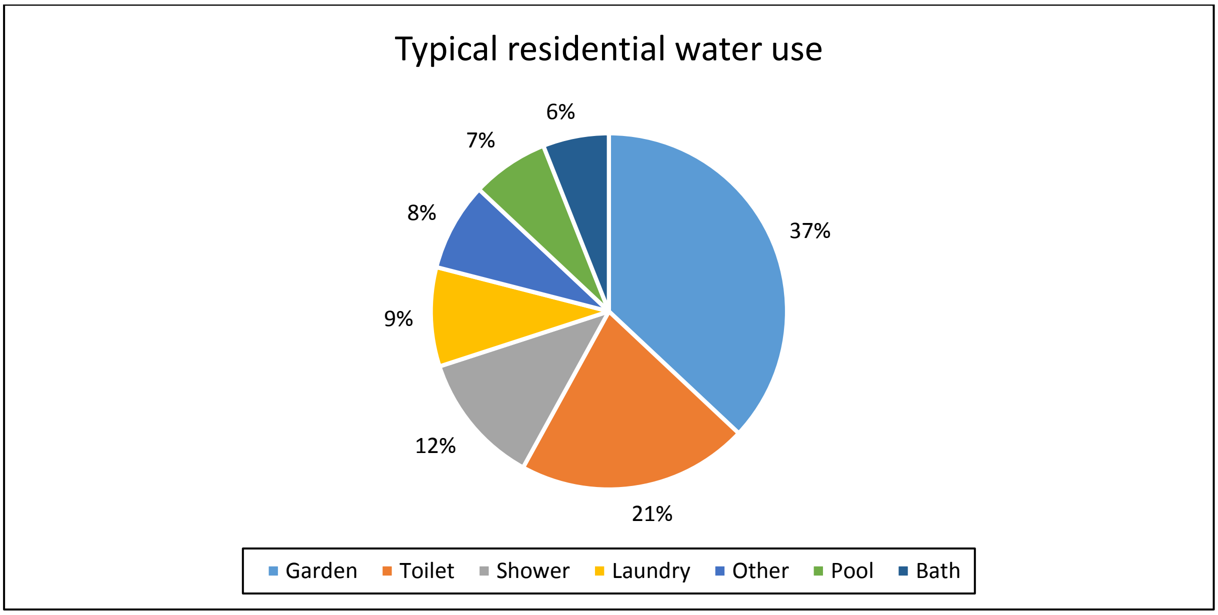

Figure 2.3: Typical residential water use from Jacobs et al. (2006)

2.2.3 Residential water meter accuracy

In order to determine the water consumption of a user with complete accuracy, the installation of a water meter at each service connection is required, and that water meter needs to be read periodically. Water meters are basic instruments that play an integral part in the management of the amount of water being supplied to an end-user. As with any measuring device, a water meter does not always register the exact amount of water being consumed. Inaccurate water readings can be ascribed to the fact that a water meter has a certain range within which it operates optimally, as water meter performance diminishes at lower flow rates. The performance of a water meter may also diminish with time as a result of aging (Arregui *et al.*, 2003).

Although the water use data to be used in this study would be screened through a cleaning process, the data would almost certainly still have a small degree of inaccuracy due to slight inaccuracies of the recorded readings.

2.2.4 Water demand studies in South Africa

One of the earliest studies on water demand in South Africa was conducted by Garlipp (1979). Water use of various cities in South Africa was studied. Data was sourced from water meter readings and water meter books in the cities of Pretoria, Bloemfontein, Cape Town, Port Elizabeth and Durban. As part of the work by Garlipp (1979), seasonal variations and related water demand patterns were investigated. Household size was found to be the parameter most influential on water demand. Garlipp (1979) also indicated that an increase in per capita water demand was related to an increase in stand area and household income. In addition, household size and per capita water use were found to be inversely related.

Soon after, a guideline was compiled by the Council for Scientific and Industrial Research (CSIR) with the aim of providing information with regard to engineering services in residential areas (CSIR, 1983). The guideline has been revised several times since. However, Van Zyl *et al.* (2007) noted that the average water demand estimation guidelines from the most recently published CSIR guideline (CSIR, 2003) have remained unchanged since first published.

Stephenson and Turner (1996) conducted a study on areas in Gauteng, which was based on the income of a water consumer. Four different categories were included in the study, namely: Very low income areas, low income areas, medium income areas, and high income areas. Water supply into these areas was measured with water meters and data loggers. Findings from the study were compared to the guidelines provided by CSIR (1994). It was found that the low income areas did not fall within the provided guidelines. The authors` overall conclusion was that stand area had a direct influence on water demand. It was also confirmed that income, population density, supply type and housing type can influence water demand.

In a similar study done on high, medium and low income water consumers by Van Vuuren and Van Beek (1997), a positive relationship was found between residential water demand and household income, with high-income households consuming significantly more water than middle- and low-income households. It was also found that climate, more specifically referring to rainfall and temperature, had a significant influence on water use patterns. The influence of climate on low income water use however, was negligible as this type of consumer did not have outdoor facilities or areas on which to use water. The study also compared its findings with the guidelines presented in CSIR (1994) and found that the daily water use for the Pretoria region investigated was less than the prescribed water demand guidelines for all of the income based water consumer categories.

Van Zyl et al. (2003) did an investigation on four different parameters that influences residential water demand, named: elasticity of water, pressure, income and stand area. The study made use of end-use modeling. End-uses were grouped into indoor consumption, outdoor consumption and leakages, and also distinguished between townships and suburbs based on property valuations. The study found that household income, stand area and pressure had positive water demand elasticities, which means that an increase in income, stand area or pressure resulted in an increased water demand. Furthermore, it was concluded that water price had the biggest influence on water demand patterns (Van Zyl *et al.*, 2007).

Jacobs *et al.* (2004) suggested a single-coefficient model that relates water demand to stand area. A strong correlation was noted between residential water demand and stand area. Three different single-coefficient models for three different South African regions namely: Coastal winter rainfall region, Inland summer rainfall region and Coastal all-year rainfall region, were contributed. The suggested model guidelines were also compared to the guidelines suggested in CSIR (2003). Jacobs *et al.* (2004) reported that the guidelines by CSIR (2003) were too conservative and could lead to over-design and unnecessary expenditures by water authorities.

Husselmann (2004) estimated the independent effects of stand area and stand value on water use patterns. Even though no direct relationship could be determined between occupants` income and stand value, it was found that stand value gave a good indication of income. The study concluded that stand area was a better indication of water demand. Stand value played a part in the positioning of the developed water demand guidelines between the upper and lower bounds of the suggested guidelines. These were also compared to the guidelines suggested in CSIR (2003) and as for the study of Jacobs, the study also found that the proposed minimum AADD was lower than CSIR (2003). Significantly, the maximum lower bound value of Husselmann`s guideline is lower than the minimum value of the lower bound of the CSIR (2003). It was therefore also concluded that the guidelines prescribed by CSIR (2003) would have the effect of over designing water supply infrastructure, leading to over expenditure.

Husselmann and Van Zyl (2006) investigated the effects of stand area and income on water use using stand value as a surrogate for income. Although a strong link between stand area and income was found, it had been concluded that stand value was too variable to use as a parameter in a design guideline. It was thus concluded that stand area provided the best basis for use in a design guideline. Again, in a comparison with the guidelines from CSIR (2003), it was found that the AADD was over estimated on a wide range of stand values. New guidelines were proposed by the authors (Van Zyl *et al.*, 2008).

2.2.5 Water demand classification

2.2.5.1 Land use classification

Water demand classification is indirectly dependant on the classification of land. The land use classification is based on a classification system, which at most basic, is a list of land uses with a distinct definition attached to each. The hierarchical list of land uses is compiled according to a methodology of how to derive land use classifications in South Africa (DRDLR, 2013). Another comprehensive methodology on land use mapping is the one developed by Australian Government-Bureau of Rural Science (2006).

Land use is mostly seen as the responsibility of town and regional planners. Studies found that land use cannot be referred to without considering the planning aspect, which introduces the legal frameworks within which land use classification should be done. For the purposes of South African land use classification, Republic of South Africa (2012) published the most recent town planning legislation and provides all necessary legislation in order to classify land use. The guideline lists 15 major purposes of land use which can be divided into the different categories of water demand (refer to §2.2.5.2). The 15 major land use purposes are as follows: Agriculture, Business, Commercial, Community, Conservation, Education, Government, Industry, Institutions, Mining, Public, Recreation, Residence, Transport, as well as any other purpose as may be prescribed.

2.2.5.2 Water demand categories

Water consumers are often distinguished as belonging to one of two main categories namely residential and non-residential water consumers, of which non-residential consumers are then divided into sub categories such as industrial, commercial and institutional sectors (Scheepers, 2012). According to Van Zyl (1996), non-residential water consumers are very difficult to classify. As residential consumers are the main type of water users, it has become common to classify any consumers other than residential water consumers as belonging to the non-residential category. Van Zyl (1996) suggested that municipal water users can be classified under seven different user categories, according to the purposes of their land use. The 15 major land use purposes (as discussed in §2.2.5.1) therefore corresponds to either one of the seven user categories, or to one of its sub categories.

Residential

Residential water use is defined as water used for household purposes. These include washing, cooking, sanitation, watering of gardens and routine filling of swimming pools. Residential demand varies with time. Water use is usually at its highest in the morning and evening hours of the day, as consumers either prepares for work, or arrives home from work (Van Zyl, 2006).

As residential areas are the category with the highest water use, this category is sub divided into four sub categories as follows:

- Large Residential areas
- Medium Residential areas
- Small Residential areas
- Low Cost housing areas

A residential area is typically sub categorised based on the average amount of water consumed per house within the area by means of a unit water demand table. As for typical residential houses, three different categories were created as these houses tend to vary significantly in size. However, LCH areas are homogeneous in size and appearance, and therefore comprise of only one category.

Trade

The Trading water use class includes offices, shops, restaurants, hotels and institutions. Demand usually varies according to trading hours and business types.

Industrial

This class is usually factories and industries which vary from water intensive users to consumers not using water at all. Demand usually varies according to trading hours and industry type.

Recreational

The recreational water use class includes private and public sports facilities, clubs and organizations. The main water demand for this class is over weekends, but demand may also be expected on weekdays.

Agricultural

The agricultural water use class includes farming and other agricultural activities which consume municipal water. These activities consume water at a relatively constant rate.

Public

This class is used for cities having a municipally owned and operated system and is often not metered (Larson and Hudson, 1951). Public use includes water used for firefighting, testing of fire hydrants, maintenance, public buildings, parks, public water features and other such purposes. Public water demand is usually small in comparison to other types of consumption.

Losses

These losses comprise the water lost as a result of leakage from water mains and fittings, overflow of reservoirs, unregistered or illegal connections and under-registration of flow meters. McKenzie *et al.* (2012) suggested that unaccounted-for water should be reduced from an average of 37% to 15% of the total amount of water that is metered in the following 10 years. Leakages differ from one network to another, but are usually highest during the night time when other demands are at a minimum and, conversely, the pressure in the system is at maximum.

2.3 Factors affecting water demand

2.3.1 Water price

This study considered the price of water as a highly influential factor in residential water demand. The general understanding regarding water price is that a higher price relates to lower water use. This economic perspective is not completely correct in the sense that water is essential and irreplaceable. Residential water use is often classified as price-inelastic, which means that the decrease in demand is relatively lower compared to the increase in price (Corbella and Pujol, 2009:300). The main reason for this classification is the fact that nothing can be substituted for water. In addition, low levels of concern are generally shown about the rates of water use as uninformed consumers disregard water tariff prices or the fact that water bills make out a relatively small fraction of the average income per household (Saleem, 2012:7).

2.3.2 Household income

It is widely accepted and empirically demonstrated that residential water demand is correlated with water price. A general assumption is that the greater the wealth, the higher the living standards, which implies a higher quantity of water use. In addition, a higher income also implies a higher probability of outdoor water use, as people with a higher income will tend to the need of watering lawn gardens and swimming pools (Corbella and Pujol, 2009:301). Higher income houses are also less concerned about the cost of water (Marella, 1992).

2.3.3 Demographic variables

Demographics relate to the structure of populations and are based on age, race, gender, economic status, level of education, income level and employment, among others. A household is increasingly seen as one of the key inputs in the study of demographics (Corbella and Pujol, 2009:301). Recent research shows that household water demand is influenced by differences in family size, age of consumers and other demographic variables (Saleem, 2012:11).

The size of a household, referring to the number of people living within a household, influences water use in a number of different ways. A number of researchers (Edwards and Martin, 1995; Jacobs and Haarhoff, 2004; Scheepers and Jacobs, 2014) have reported positive correlation between household size and the use of water. Corbella and Pujol (2009) noted that larger households tend to optimise water use, meaning that the least amount of water is used per household occupant, and that an optimum household size exists. Beyond the optimum size of people per household, economy of scale seems to vanish.

A study in the USA and Canada found that each additional consumer within a household increases the household`s daily water use by 22%. Household size is not directly proportional to the amount of water being used, since, according to the economics of scale, doubling the household size will not double its monthly water demand (Hoglund, 1999). This phenomenon is due to the fact that water demand is not only family size dependant, but depends on other factors as well.

The age of water consumers also plays a big role in residential water demand. Older people seem to use less water per capita than the young. With the influence of the built environment, households with children and teenagers use considerably more water on activities related to outdoor uses. Older people also tend to use water more sparingly than younger people (Corbella and Pujol, 2009:302).

A study conducted by Hanke and de Mare (1982) found that children used almost double the amount that adults use. In another study, Lyman considered children, teenagers and adults, in which teenagers were considered to be any age between 10 and 20. Lyman (1992) found that children were the highest consumers while teenagers were the age group with the lowest use. Lyman (1992) also noted that the water use of a child is 2.5 times that of a teen and 1.5 times that of an adult.

2.3.4 Stand area

Studies show that stand area is one of the parameters most influential on residential water demand (Van Zyl *et al*., 2007). A commonly used South African guideline for water demand estimation was solely based on stand area (CSIR, 2003). Two recent studies confirmed that residential stand area is positively correlated to water demand (Jacobs *et al.*, 2012; Griffioen *et al.*, 2009). The South African water demand guidelines have been based on stand area since 1983 (CSIR, 1983), if not earlier.

2.3.5 Climate

Climate can be described as the composite or generally prevailing weather conditions of a region, being the average temperature, air pressure, humidity, precipitation, sunshine, cloudiness, and winds, throughout the year, over a series of years. According to Marella (1992), the two climate variables with the greatest influence on water consumption are rainfall and temperature.

Rainfall mainly affects outdoor activities, and therefore has more influence on outdoor water use. The amount of precipitation mainly influences the need to water plants and lawn. In addition, people live more indoors than outdoors in times of rain. Wet outdoor conditions also lead to a significant decrease in outdoor water use due to a lower need of water for the purposes of swimming pools and other elements of the built environment.

Temperature has also been shown to impact water demand. On days with higher temperatures, the watering of gardens increases, swimming pools are most used, and more water is consumed for the purposes of personal hygiene. The main cause of this phenomenon is the fact that higher temperatures imply more evapotranspiration from both humans and plants.

2.3.6 Water losses and minimum night flow

Water loss is a universal problem, as it occurs in all distribution systems. Water losses vary according to the characteristics of the pipe network and other local factors. The three main components of water loss are as follows: Authorised metered, authorised unmetered and the remainder, which represents all unaccounted-for water, and is often referred to as the real and apparent losses. Real losses are those where the water has left the system and has not been used in any way, and will be considered in this study (McKenzie, 1999).

Minimum night flow (MNF) can be defined as the lowest consistently repeatable flow rate into a zone or district, measured during the period of lowest consumption (typically 00:00 to 04:00). It includes legitimate water use, burst leakage and background leakage. Real losses can therefore be calculated by subtracting the legitimate water use from the MNF (McKenzie, 1999).

2.4 Variation in water demand and related demand patterns

Temporal variation in water demand is caused by many contributing factors. The time of the day when water is demanded by a consumer drives the diurnal water use pattern. However, as the number of consumers increases, consumer patterns become more predictable, as groups of consumers tend to have periodic activities. An assumption made by Trifunović (2006) was that the demand cycle for each consumer in a large group would be the same.

2.4.1 Daily variations

The typical daily water use of a residential house shows two distinct water demand peaks. The first peak typically occurs in the morning (between 06:00 and 08:30), and the second in the evening (between 16:00 and 20:00). As can be seen in Figure 2.4, two distinct water demand peaks is the general trend for most residential households, corresponding with the working occupants` rush to get to work in the morning. In the evening, circumstances are more relaxed, implying a less-pronounced peak.

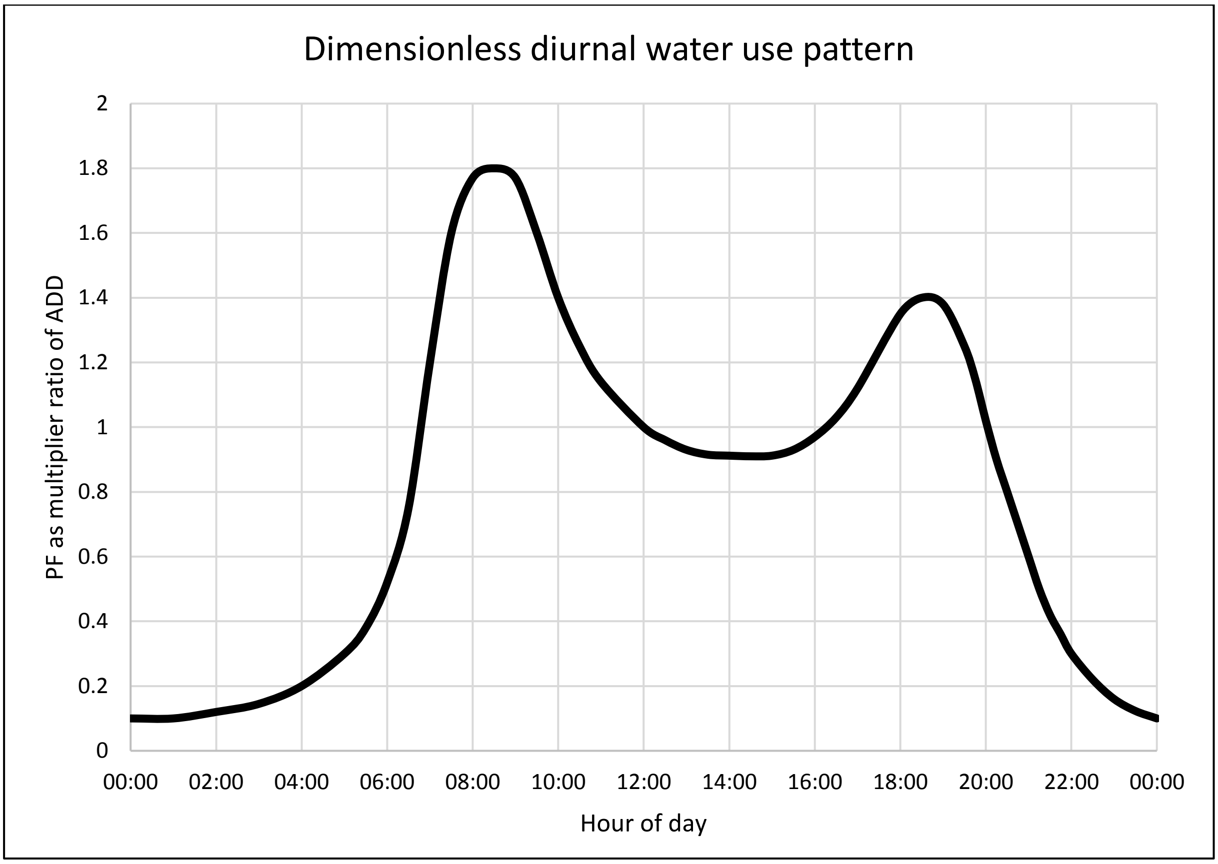

Figure 2.4: Typical diurnal water use pattern

2.4.2 Weekly variations

Weekly demand patterns are influenced by working and non-working days. Work days, which are usually from Monday to Friday, have a distinct pattern, and differs from the non-working days. On non-working days, which are usually on Saturdays and Sundays, water use patterns are spread more evenly throughout the day, since people tend to be home for longer during the day. Peak demands are therefore expected to be lower over weekends. The weekday morning rush generally reaches the peak more rapidly than weekend days. A less pronounced peak combined with relatively higher use throughout the day is often observed for either high income houses with housemaids, au pairs or automated garden irrigation systems, or for lower income houses where non-working house occupants are home during the day.

2.4.3 Monthly variations

Water use is significantly influenced by weather, and factors that accompany the weather. Water use tends to be fairly constant across the months of April to October, with an increase observed from December to March in South Africa. The constant water use months fall in the winter; the months of increasing water use fall in the summer. Monthly water use variations are seasonally driven.

2.4.4 Seasonal and quarterly variations

Variations in water demand are noticeable throughout the year and can therefore be referred to as seasonal variations. Higher temperatures during the summer months lead to a higher outdoor water use, which causes a distinct rise in unit consumption per capita. During hot seasons, an increase in demand may also result from an increased number of consumers, which is a typical phenomenon for holiday destinations. As can be seen in Figure 2.5, seasonal variations refer to only summer and winter, and not all four seasons of the year. In addition, it can also be noted that winter has a higher morning peak than in the summer, and conversely, the winter afternoon peak is lower than in the summer.

Quarterly variations occur according to the change of seasons. Typically, the June to August and September to November quarters have the lowest water use, as these three-month intervals are during winter and spring. The December to February and March to May intervals, however, are usually shown to have higher water use, as these intervals fall in summer and autumn. The establishment of quarterly variations is usually done in countries using a quarterly billing system, as quarterly is the smallest interval at which billing data is read in these regions. Note that for registering quarterly variations, a year is divided into four quarters according to seasons, rather than according to traditional terms.

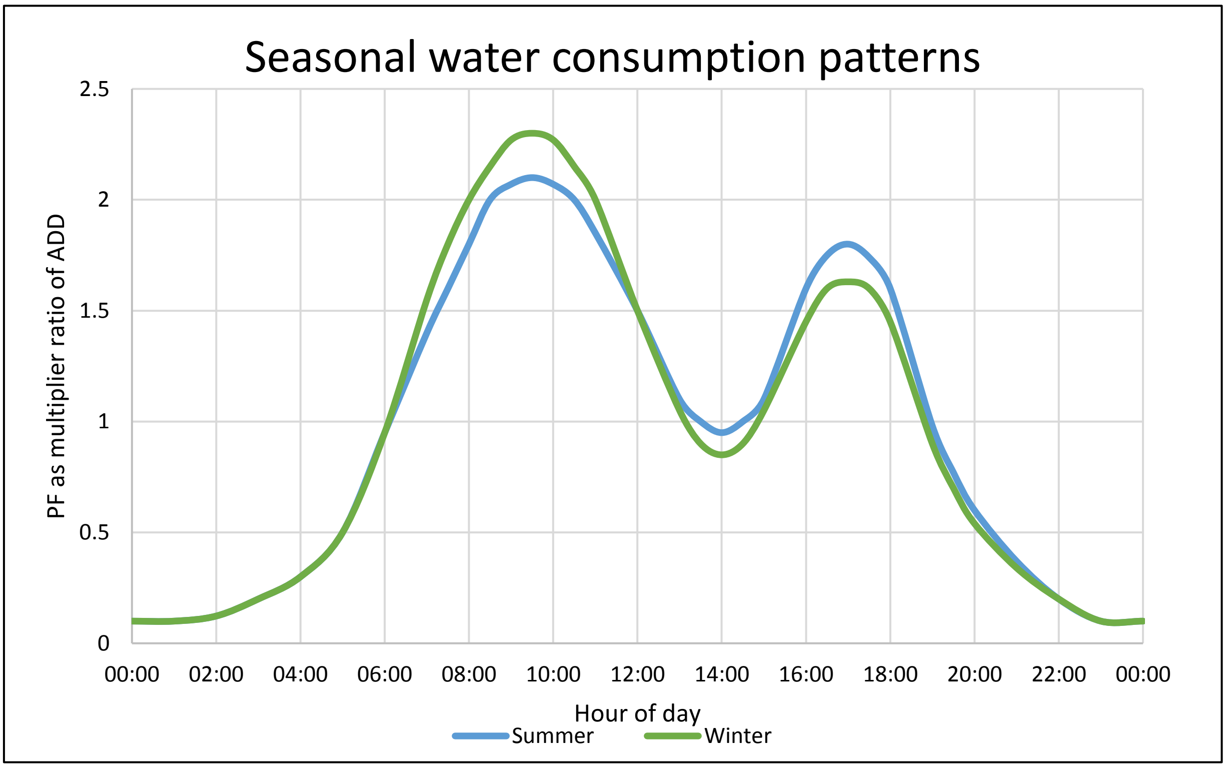

Figure 2.5: Comparison of summer and winter diurnal water use patterns

2.4.5 International water demand patterns

The impact of diurnal water use patterns on water supply network design was studied by Lucas *et al.* (2010:73) in Australia. Water demand was determined at an allotment by means of PURRS, which is a unique probabilistic and behavioural framework for continuously simulating the dynamics of water use at the allotment. The diurnal water use patterns used in the allotment water balance are given in Figure 2.6 . As can be seen, pattern 1 represents a typical diurnal pattern for a three-person household and pattern 2 for a four to five-person household.

In New Zealand, Heinrich (2007) monitored water end-uses and studied improved efficiency. The study distinguished between winter and summer for both the monitoring periods and the number of households monitored. The winter data was collected over 72.6 days from 12 sample houses and averaged at a daily use of 439 ℓ with an average of 2.7 people per household (PPH). The summer data was collected over 89 days from 11 sample houses and averaged at a daily use of 525 ℓ with an average of 2.7 PPH. Winter and summer water use patterns were obtained from the summation of all end-uses, and can be seen in Figure 2.7. As noted earlier, the winter morning peak is higher than the summer. Conversely, the winter afternoon is lower than the summer afternoon peak.

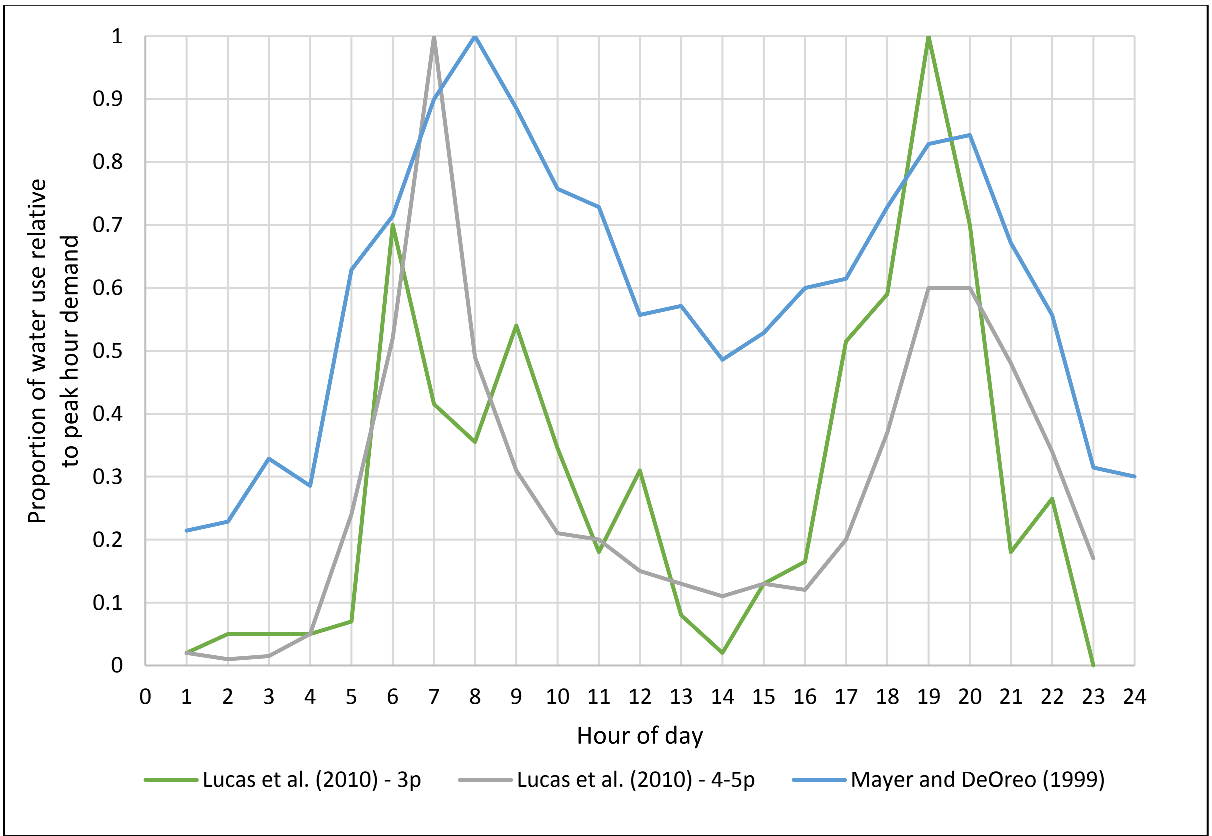

Figure 2.6: Water use patterns expressed as a proportion of peak hour demand

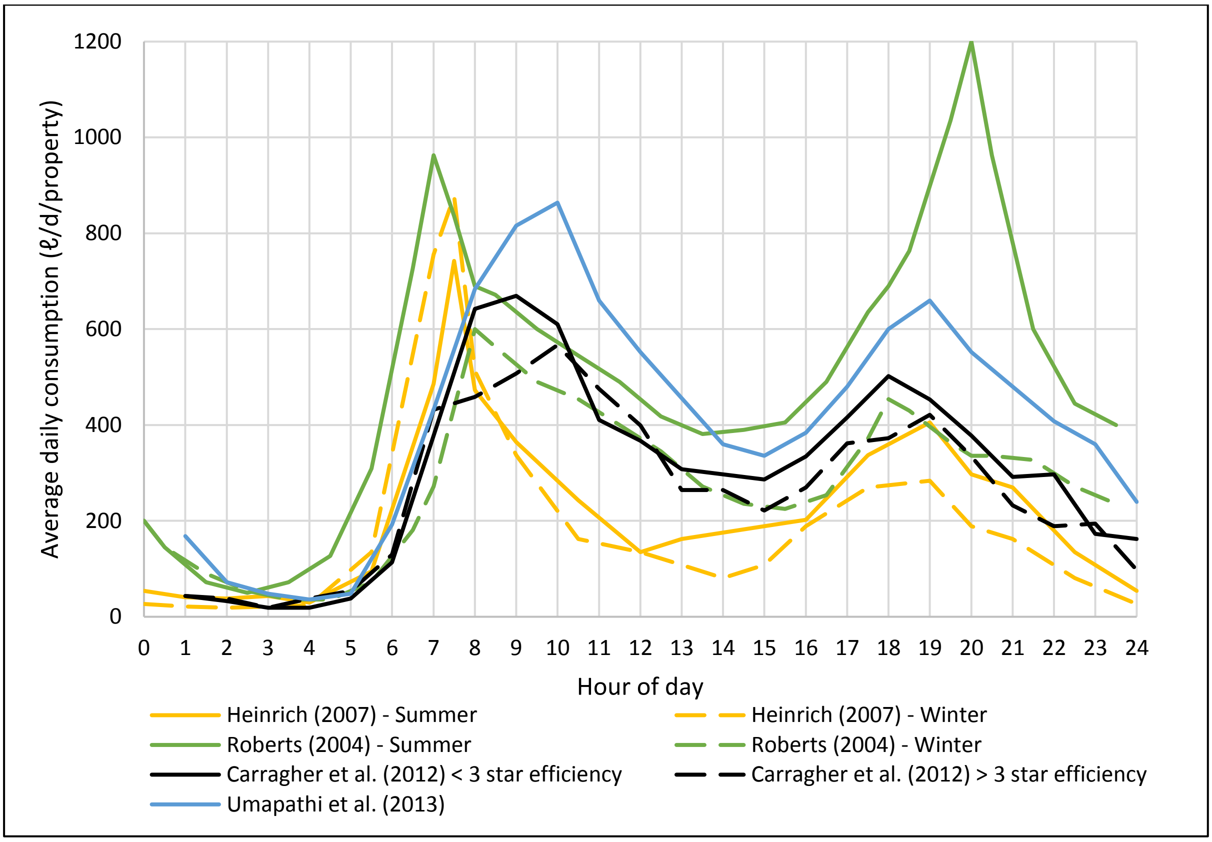

Figure 2.7: Average water use patterns expressed in terms of ℓ/d/property

Umapathi *et al.* (2013) conducted a study on 20 houses in Australia. A water use pattern was constructed by combining the use from a water main with rainwater harvesting at each house. The diurnal pattern is a completely valid residential water use pattern, as the water used from the main water supply and rainwater tank was done separately. Water usage was measured from either the water main for most indoor water uses, or from the rainwater harvesting tank, which was used mostly for outdoor uses. The combined diurnal water use pattern can be seen in Figure 2.7. An average annual water use was obtained as 40 kℓ/household for the outdoor usage and 111 kℓ/household for the indoor usage, giving a total of 151 kℓ/household. The average daily water use reported by Umapathi *et al.* (2013) was 109 ℓ/household and 304 ℓ/household with a total of 413 ℓ/household/day.

Mayer and DeOreo (1999) collected water use events from 1 188 residences in 12 different study sites across North America. The average annual water use was calculated from historic billing records from the 12 study sites, and was found to be 536 ℓ/household. The indoor water use was found to be 42% versus the outdoor use of 58% across all study sites. Usages were combined to construct the diurnal water use pattern as follows in Figure 2.6 (Mayer and DeOreo, 1999).

DeOreo *et al.* (2016) provided an updated and expanded assessment of water use. The updated study included more varied study locations. However, the sites showed significant variation in climate and weather. It was therefore assumed more appropriate to compare only indoor water use between the two studies. Since the indoor end-uses from the 1999 and 2016 studies were compared separately, no diurnal water use patterns were constructed. In the comparison between the indoor water uses from the two studies, however, an overall decrease of 22% per household was found over 17 years.

Roberts (2004) collected end-use data in Australia with the purpose of comparing actual measured results with survey based estimates and to enable informed design and assessment of demand management programmes. End-use data was collected as part of the study by Roberts (2004) over a total of 2 394 days on 93 houses in the summer and 81 houses in the winter. The average daily water use was obtained as 784 ℓ in summer, compared to 511 ℓ in the winter. These measured residential end-uses were combined to construct the following diurnal water use pattern presented in Figure 2.7.

In a similar study on the measurement of residential end-uses in Australia by Carragher *et al.* (2012), done with the purpose of quantifying the influence of residential water use on average diurnal water use patterns, 191 households were studied. The average daily water use was obtained as 333.7 ℓ/household, which gave an average daily use of 132.6 ℓ/person at an average of 2.5 PPH. The following diurnal patterns were set up according to the WELS efficiency ratings, as explained by Carragher *et al.* (2012). Under the WELS Australian standard, product suppliers are required to label water end-use appliances with a star-rating, as well as water efficiency information. To gain a star-rating, appliances must pass comprehensive and consistent tests, and are rated in half star increments up to a maximum of 6. The investigated homes were categorised as those with less than 3 star efficiency and greater than 3 star efficiency. The end-uses from the investigated homes were added according to the star-rating clusters with subsequent patterns shown in Figure 2.7.

2.4.6 South African demand patterns

GLS Consulting published diurnal water use patterns for LCH developments. Residential diurnal water use patterns were also presented by GLS for low, medium, and high water use, as well as business/commercial/ industrial patterns for medium to large amounts of water use (Compion, 2010). The focus in this review, however, was on the South African LCH average diurnal water use pattern. As can be seen in Figure 2.8, the LCH pattern of GLS from Compion (2010) differs from the other residential water use patterns with an absence of the morning and evening peaks.

The LCH water use peak also occurs at a different time of the day, around mid-day. The gradient of the LCH peak is not as steep as residential peaks usually are. The LCH peak starts in the morning and gradually increases to 11:00, where it stays relatively constant for about 5 hours. The water use then gradually decreases to the minimum value late at night. Unemployed occupants start their day a bit later than the average working person. Water is then used increasingly towards the afternoon, for uses such as cooking, dishwashing and laundry. The water supply to LCH units is typically not heated, meaning that water used for bodily cleansing is postponed to the hours of the day when the ambient temperature is warmer.

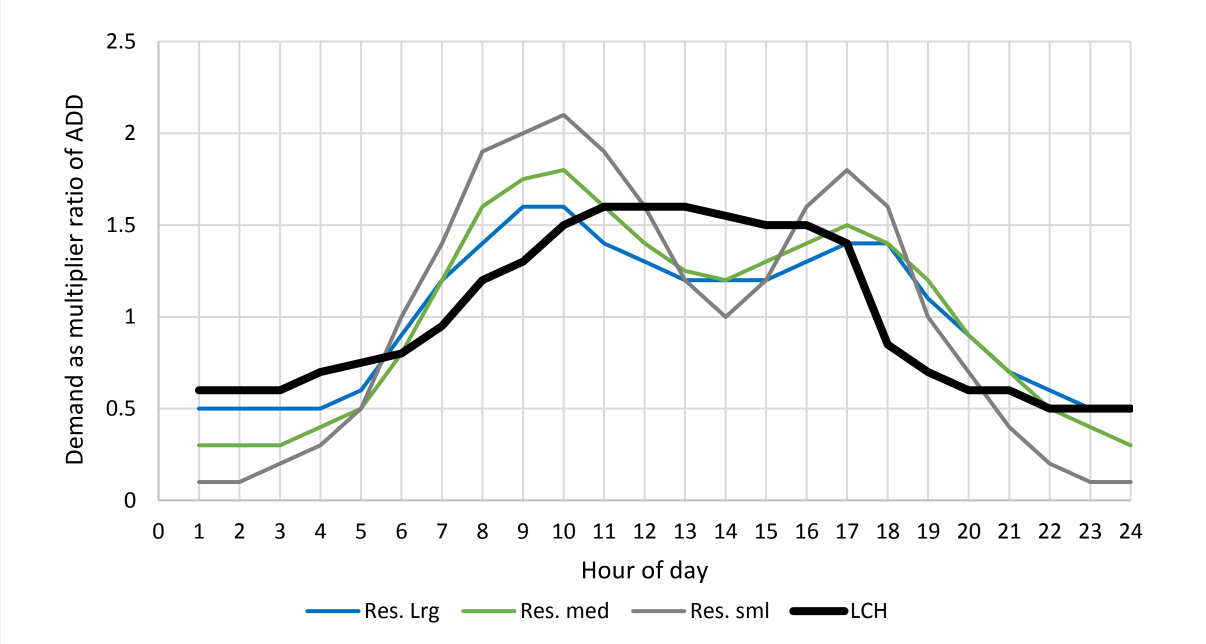

Figure 2.8: South African average diurnal water use patterns (Compion, 2010)

2.5 Peaking factors

2.5.1 Overview of peaking factors

Peaking factors (PFs) were defined by Diao *et al.* (2010) as the ratio of the maximum flow during a specified time to the average flow during an extended period of time. PFs are used to estimate the peak flows when the average flow is known. Peak flows are regarded as one of the most important factors in the design of a water distribution system. PFs are highly related to the number of consumers, the service areas, and the duration of the peak flow of a water reticulation system (Diao *et al.*, 2010).

PFs generally tend to increase as the number of consumers decreases (Diao *et al.*, 2010). Barrufet (1985) found that PFs increase from 1.5 for 100 000 consumers up to 98 for as few as only 2 consumers per household. Tessendorff (1980) also found a strong inverse linear relationship between the number of consumers and PFs, as well as between flow and pressure.

PFs increase with the decreased δt, which implies that smaller δt leads to larger PFs (Johnson, 1999:112). For water supply areas, PFs follow the same tendency as an increase in the area to be supplied will decrease the PF. This can be ascribed to the fact that smaller supply areas imply fewer water users, which makes the prediction of variation in water use even harder (Diao *et al.*, 2010).

PFs can also be expressed as a function of average flow in the form of a linear or algorithmic expression. The determination of PFs for water supply systems is not amenable to theoretical predictions and cannot be calculated by authoritative calculation methods. The estimation of PFs therefore has to be done according to field measurement records or empirical calculations (Johnson, 1999:111).

2.5.2 Peaking factor studies in South Africa

The CSIR (1983) guidelines have been in use since 1983 and, although revised a number of times since then, few guidelines on PFs have changed (Van Zyl *et al.*, 2007). A PF guideline presented in CSIR (2003) for the purpose of township development is given in Figure 2.9.

From Figure 2.9, the instantaneous PF needs to be calculated by converting the daily water demand to equivalent erven (ee) (where ee = 1 kℓ /d), which can then be used to obtain its corresponding PF. As stated, the CSIR (2003) refers to instantaneous PFs, but does not define what instantaneous means. Tessendorff (1972) defined a PF as follows: Integration of the flow q over a section of a hydrograph (period of observation) provides the mean value q_m for the period considered. The ratio q_{max}/q_m may be taken as the PF.

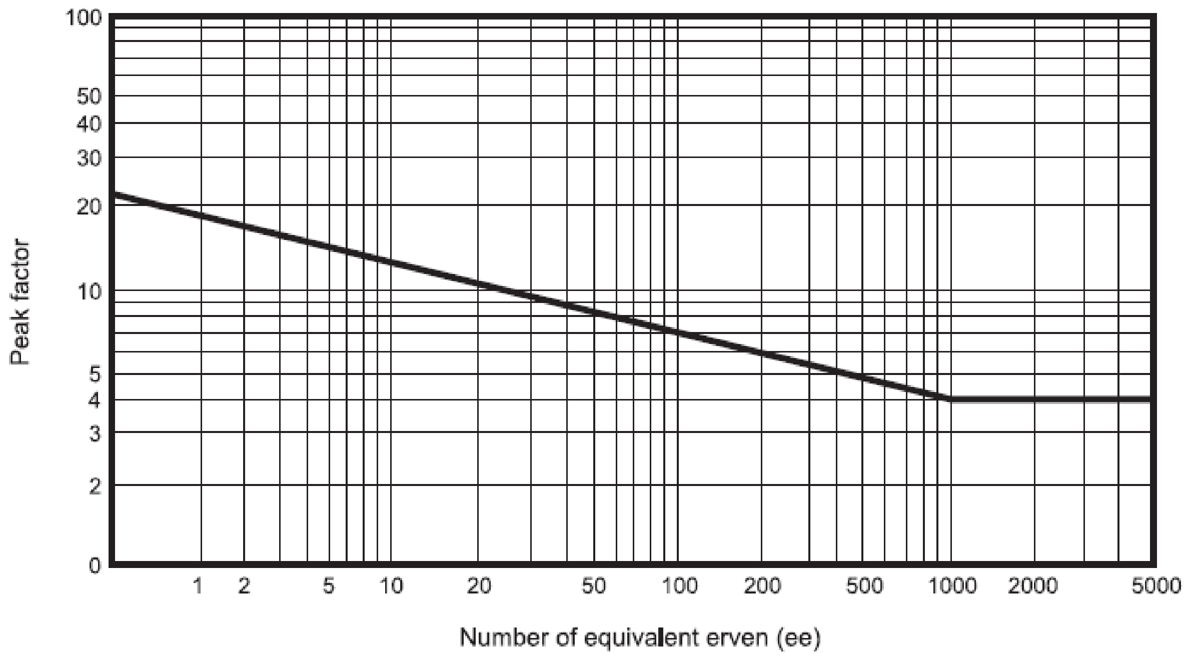

Figure 2.9: Factor for obtaining the peak flow in mains for low cost housing, incorporating individual on-site storage (CSIR, 2003)

Defining a PF in terms of a period is crucial. Booyens and Haarhoff (2006) stated that without defining the meaning of instantaneous, the concept of an instantaneous PF is invalid. In addition, several authors have found that guidelines on PFs in the CSIR (2003) are too conservative. The findings of these authors and other similar studies are discussed.

In a study done by Hare (1989), Hare contributed two measured PFs. Only two out of the three residential areas studied provided decent results. Possible explanations for the lack of data integrity included: Battery failure, blocked water meters, lack of accuracy and late delivery of equipment. The two areas considered consisted of the equivalent of 62.5 and 820 erven respectively. Each area was monitored with a single meter and data logger and was recorded at 10-minute intervals. PFs with values of 6.35 and 3.98 were obtained from the 62.5 and 820 ee respectively. However, Hare declared the study as incomplete and therefore inconclusive.

In a study done by two collaborating companies, Ninham Shand and GLS Consulting, a strategy and master plan for water supply, storage and distribution in the East Rand region was developed and published in 1995. The PFs that were used in the study are given in Table 2.1 (Vorster *et al.*, 1995:3).

Table 2.1:Peak factors used as a ratio of AADD (Adapted from Vorster et al., 1995:3)

Predominant land use in area under consideration	AADD for area (Mℓ/d)	Peak day factor (PDF)	Peak hour factor (PHF)
Low density residential	<1	2.30	5.50
	1.0 - 5.0	2.20	4.50
	5.0 - 20.0	2.00	3.90
	>20.0	1.80	3.30
Medium density residential	<1	2.30	4.60
	1.0 - 5.0	2.00	4.00
	5.0 - 20.0	1.80	3.30
	>20.0	1.70	2.90
Industrial/ Commercial	<1	2.00	3.40
	1.0 - 5.0	1.80	3.00
	5.0 - 20.0	1.75	2.80
	>20.0	1.70	2.60

Van Vuuren and Van Beek (1997) did a study on the water use in the city of Pretoria. The study investigated residential water use from 1982 to 1994 for 53 reservoir supply areas. Although all 53 reservoir supply areas were used in the development of water demand guidelines, only one reservoir could be used for the development of PFs, as information on the other 52 reservoirs was used for different purposes. The reason for using only one reservoir was the fact that hourly data was required for the generation of PFs. The only reservoir considered had data available from July 1995 to

October 1995. A PF of 2.75 was obtained, which is much lower than the corresponding PF of 4 from CSIR (2003).

Van Zyl (1996) demonstrated that existing water use patterns can be analysed to generate other water use patterns, for water supply areas of similar type, but different size, by means of computer. This implies that demand patterns can be constructed by using existing water use patterns from a supply area with similar characteristics. Computer generated demand patterns could then be used to generate new PFs which could be used in the design of the water infrastructure.

An important characteristic of water use is that, except for leakages in a system, water use is not a continuous process. It should therefore rather be seen as a combination of a great number of water withdrawals from a water reticulation system. Each value on a water demand pattern gives a good indication of the number of utilities that are active at a certain time of day (Van Zyl, 1996).

Van Zyl (1996) stated that a water demand pattern can be expressed as a probability pattern which indicates the probability of the average utility in the system being active. These probable-demand patterns can then be used in a computer simulation in order to generate a new water use pattern.

Van Zyl`s simulation was written to simulate the use of a utility for each minute of the day. The simulations made use of a random function, which estimated whether a utility was active (open) or inactive (closed). Figure 2.10 shows that solid lines, which represent active utilities, were of greater density in peak periods. The simulation was repeated for 10, 100, 1000 and 10 000 utilities, as can be seen in Figure 2.11. In this way, a diurnal water use pattern can be created for similar new areas, from which design PFs can then be calculated for new developing areas. The resulting PFs from the simulations done by Van Zyl (1996) for 100 000 utilities are shown in Figure 2.12.

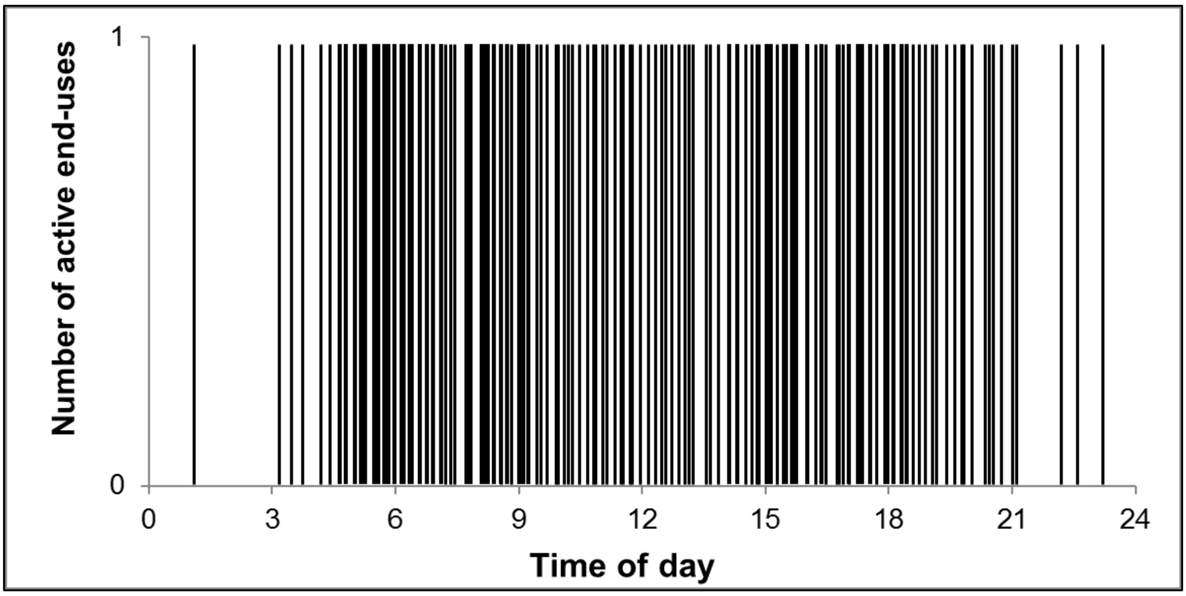

Figure 2.10: Results from the end-use simulation for one consumer (Van Zyl, 1996)

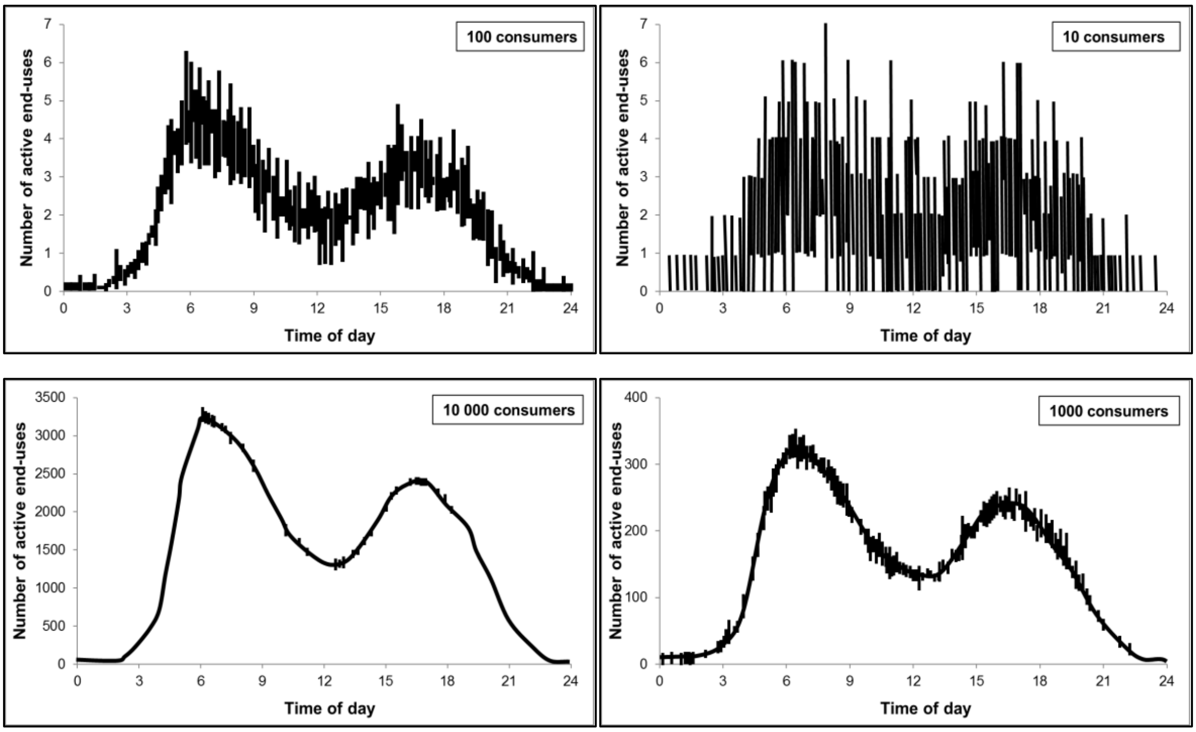

Figure 2.11: Results from simulations for many consumers (Van Zyl, 1996)

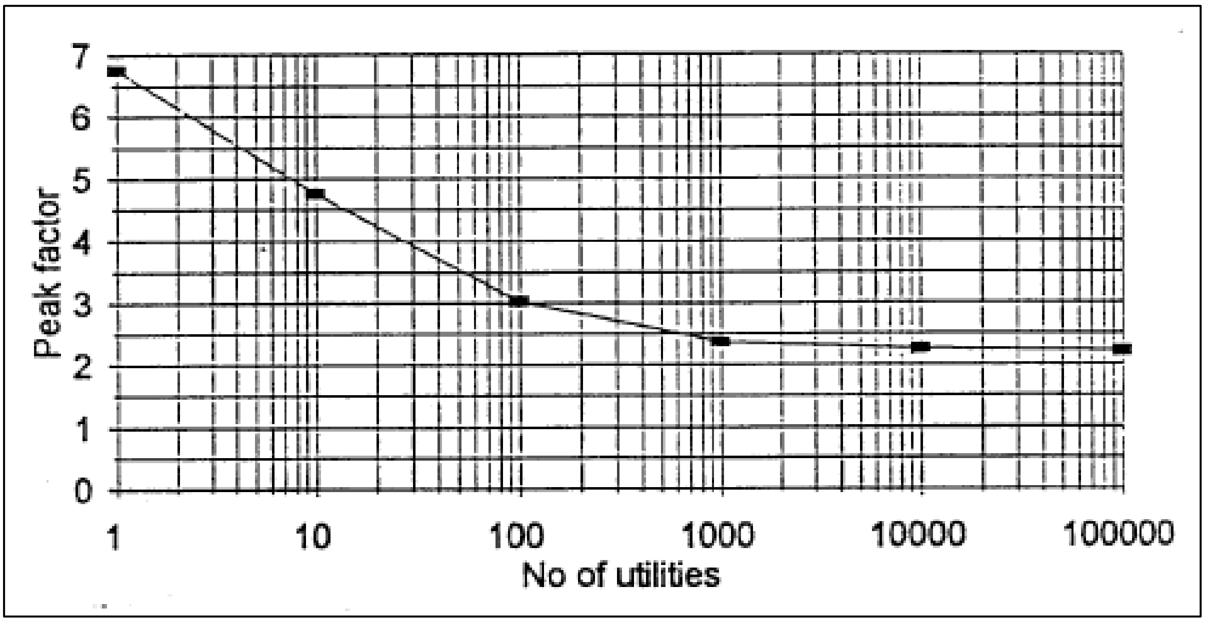

Figure 2.12: Resulting peaking factor values for up to 100000 consumers (Van Zyl, 1996)

Turner *et al.* (1997) measured water use at 15-minute intervals in 14 different areas over 20 months in 1997. As previously discussed, the diurnal patterns were generated from the recorded water use for different income level categories. A total of 13 PFs were calculated from the 13 areas studied, all of which were lower than the corresponding PFs from CSIR (2003).

Johnson (1999) studied the degree of utilisation of water supply systems, which was also described as the reciprocal of the PF. Johnson (1999) reviewed previous studies with the purpose of providing greater insight when analysing the optimal level of investment required in water infrastructure. Research showed that water supply and distribution systems have a degree of utilisation between 30% to 50%.

The degree of utilisation provides both a technical and an economic connotation to the analysis of the PFs. The larger the PF, the lower the degree of utilisation is. In addition, the degree of utilisation is closely related to the profitability of water authorities. Low degrees of utilisation imply that large capacities of water must be maintained in pipelines in order to accommodate for short intervals of peak demand.

Note that the interval for which the degree of utilisation was derived, needs to be stated next to the calculated percentage value. The degree of utilisation can be expressed as follows (refer to Equation 1):

$$Degree\ of\ utilisation = \frac{100}{peak\ factor\ or\ function} \tag{1}$$

Johnson (1999) also applied probability theory to demonstrate how a recurrence interval of peak events, together with the corresponding degree of utilisation can be used to evaluate possible alternative design and operational criteria. A better illustration for the use of this theory is given in Figure 2.13. PFs were calculated using 15-minute flows from a reservoir over a period of 120 months.

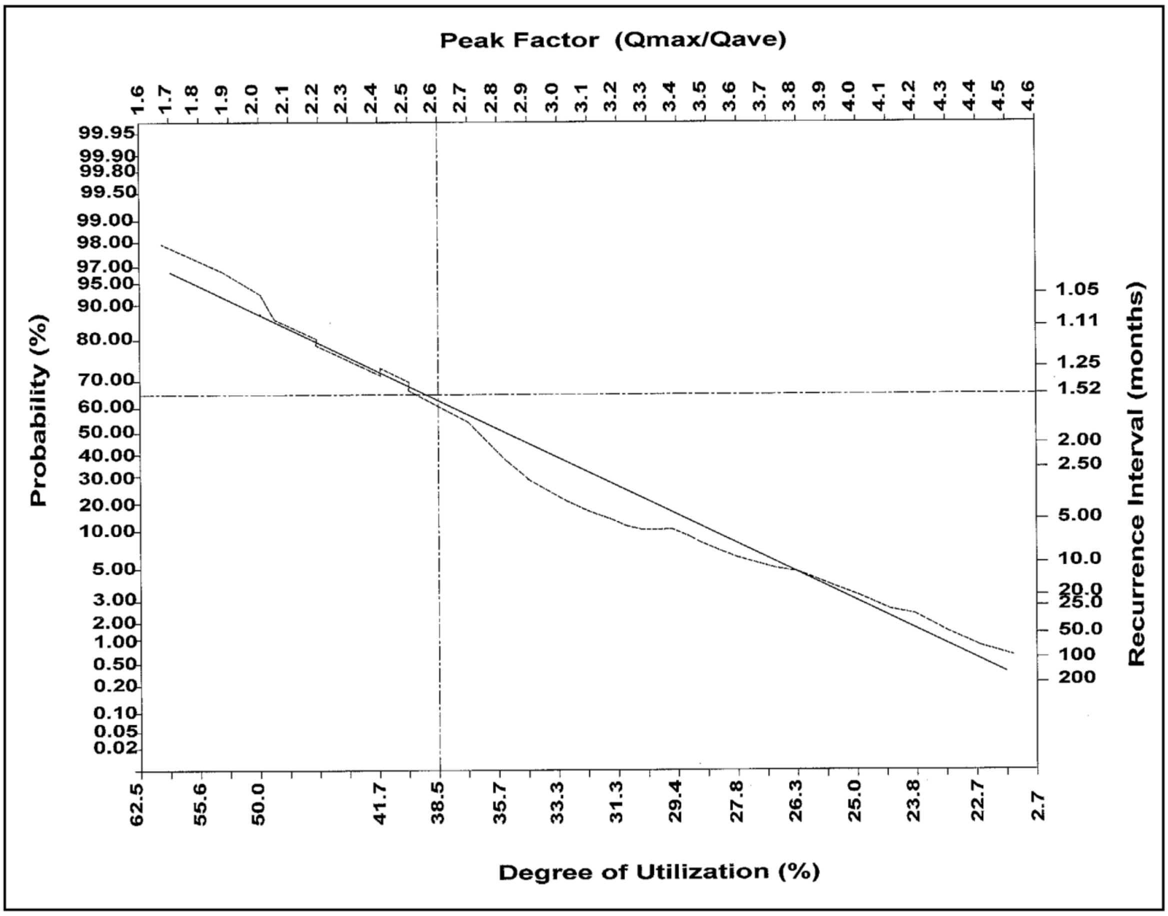

Figure 2.13: The probability-degree of utilisation peaking factor graph (Johnson, 1999)

Probabilistic PFs were also calculated by Booyens and Haarhoff (2000). The study was done on five different residential areas in Boksburg with 62, 446, 828, 1 351 and 4 585 ee respectively. The data was captured by means of three data loggers and two telemetry systems. The data obtained was specifically analysed for the purpose of calculating probabilistic PFs. The 15-minute interval PFs were calculated for 99%, 98%, 95% and 90% probabilities and plotted for the range of equivalent erven studied. These were then compared to the prescribed guidelines in CSIR (2000). Booyens and Haarhoff concluded that the guidelines in CSIR (2000) was consistently too high, in comparison with all data-driven studies, and that it was about time that it was reviewed.

Scheepers (2012) derived PFs for residential indoor water demand by means of a probability based end-use model. The stochastic end-use model was used to develop water use patterns with the purpose of calculating PFs for a range of different time values, ranging from one second to hourly PFs. The water use patterns were developed with six different end-use events from residential indoor water use in terms of water volume required, the duration and time of occurrence of each event. The probability distributions describing the end-use model parameters were derived from actual end-use recordings from a North-American end-use project.

A total of 99 500 models were executed, from which 4 950 water demand scenarios were developed. For each scenario, a set of eight different time interval PFs was derived (refer to Figure 2.14). Similar to previous studies, these results were compared to the guidelines from CSIR (2003). Scheepers (2012) concluded that a relatively small difference existed for PFs between 1 and 10 households. However, a significant difference was found for the higher range of numbers of households between 10 and 1000, as the comparative values from CSIR (2003) were found to be remarkably high.

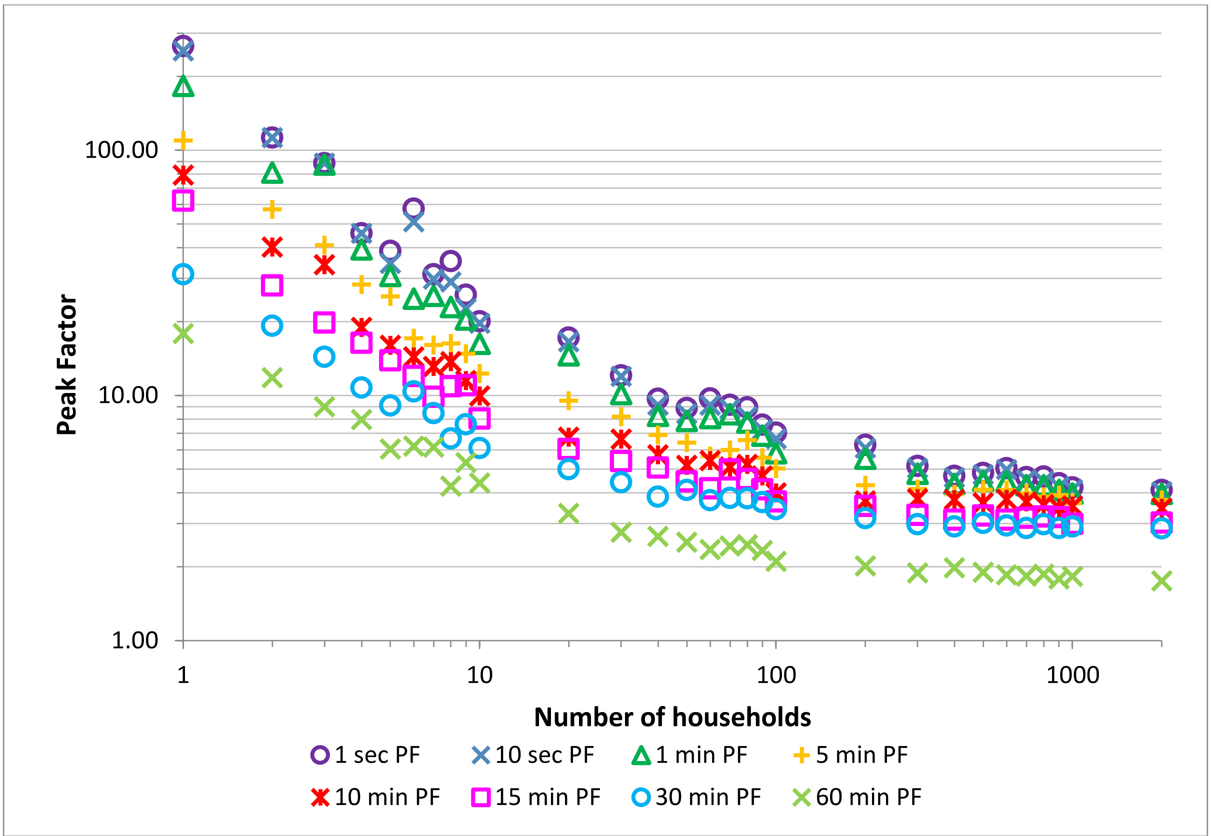

Figure 2.14: Maximum peaking factors derived by Scheepers (2012)

3. Hydraulic network modeling

3.1 Basic overview on Hydraulic network modeling

The design of potable water distribution systems has been greatly affected by the modern methods and tools available to engineers, designers and planners. As a result of the rising capabilities and advancement in computing, water network modeling now provides a fast and efficient way of predicting water network hydraulics (Newbold, 2009).

The simulation of a network model is a mathematical representation of a real system which involves the development of computerised mathematical models of treated-water distribution systems. Simulation models enable a user to simulate and analyse an existing water distribution network, or to plan, design and simulate an expanding system (Cesario, 1995). Network simulations are typically performed in the following cases:

- When the real system is not suited for experimentation or for the purpose of evaluating a system before it is actually constructed.
- In order to predict system response subjected to a wide variety of conditions without disrupting the actual system.
- To anticipate problems in an existing or proposed system before time, money and materials are invested.

Each network model has a network solver that performs calculations on a data set which describes that specific system. A network solver, better known as a network analysis package, is a computer program or package which calculates pressure, flow, head loss and velocities. A network analysis program is of no use on its own, and requires the network data set in order to run an analysis.

Data set files contain the information necessary to establish the system information and network conditions. With the use of these data files, the network solver is enabled to model the physical components of the simulated system and how these elements are interconnected within the network. Networks comprise node and link elements, the former which represent features at specific locations within the system. The link elements define relationships between nodes. Water distribution systems have a range of nodal elements, including junctions where pipes connect, storage tanks, reservoirs, pumps and control valves. Valve and pump elements are sometimes defined as links rather than nodes. Models use link elements to ‘link’ or connect these nodes as pipes. A brief summary of each modeling element and its purpose is given in Table 3.1 (Bistreceanu, 2006).

Table 3.1: Network modeling elements (Bistreceanu, 2006)

Element	Type	Primary Modeling Purpose
Reservoir	Node	Provides water to the system
Tank	Node	Stores excess water within the system and releases that water at times of high usage
Junction	Node	Removes from (demand) or adds to (inflow) water in the system
Pipe	Link	Conveys water from one node to another
Pump	Node or link	Raises the hydraulic grade to overcome elevation differences and friction losses
Control Valve	Node or link	Controls flow or pressure in the system, according to specified criteria

After the basic elements and network topology have been defined, further refinement may be made, depending on the intended purposes. There are two basic types of simulation that may be performed, according to what the modeller is trying to observe or predict.

3.1.1 Steady state simulations

Steady-state refers to the state of a system that is unchanging in time. Steady state simulations (SSSs) are typically used for systems that have achieved equilibrium. The boundary conditions of the system are defined by constant reservoir levels, water demand and pump and valve operation. However, water distribution systems are very seldomly in a true steady-state.

Steady-state simulations represent a snapshot in time and are used to determine the system behaviour under a single set of static conditions. As early modeling applications focused mainly on steady-state conditions, simulations were done on maximum-hour and minimum-hour conditions. Maximum-hour conditions refer to the maximum consumption during a one-hour period whereas minimum-hour conditions refer to the minimum consumption during a one-hour period. However, in modern times, SSSs are typically used for unique hydraulic conditions such as peak hour demand and fire scenarios at specific nodes.

In SSSs, the modeller can build on the baseline water demand by either using PFs, or assigning different demands to specific nodes. The development of improved PFs for LCH units will therefore aid in the modeling and design of this type of dwelling.

3.1.2 Extended period simulation

Bistreceanu (2006) reported that an extended period simulation (EPS) is a simulation of a system comprising a finite set of consecutive steady-state simulations, in which water demands and boundary conditions change over time. EPSs are typically used to understand the effects of changing water demand over time, the filling and draining of tanks, or the responses of pumps and valves to system changes.

As a snapshot taken at a specific moment in time may be compared to a steady state simulation, a series of these snapshots run in sequence would be an EPS. Simulations that build up an EPS are basically steady SSSs that are put together in sequence. After each SSS, the boundary conditions, which are not constant in time, are updated. After the set period of time, another time step is taken. This process continues until the simulation period ends.

An EPS can be simulated for any length of time. However, the most common EPS simulation time duration is a multiple of 24 hours. With established diurnal patterns, EPSs can be used to study temporal variation in a water distribution system.

3.2 Hydraulic modeling concepts

Hydraulic models make use of numerical equations in order to depict and simulate with the purpose of replicating the behaviour of water distribution systems (Husain, 2015). Every hydraulic element in a model influences its neighbouring element, as all of these elements are interconnected. The condition of one element must, therefore, be consistent with the condition of all the other elements (Walski *et al*., 2001). The two basic concepts which define these interconnections, better known as the governing laws of flow in a pipe, are the conservation of mass and the conservation of energy.

3.3 Applications of water distribution models

3.3.1 Master planning

Master planning is a process by which all aspects of a water distribution system are carefully investigated to determine whether major improvement projects might be necessary. In South Africa, water master planning has taken the form of establishing a model of existing infrastructure followed by the preparation of a master plan. The purpose of master planning is to define the placement and sizing of improvements and additions to the existing system to meet the requirements of the system after the expected developments have taken place (Fair and Compion, 2008). System growth and water use can therefore be projected in the future for the next 5, 10, 15 or 20 years. In the context of long-term investment planning, utilities usually develop forecasting data on the basis of water demand of the area served (Tessendorff, 1972). Water distribution models enable planners to understand the behaviour of a system and to act according to the improvements which need to be done.

3.3.2 Rehabilitation

As the water infrastructure of a distribution system age, the need to rehabilitate portions of the system increases. One of the biggest concerns in the aging of pipes is where unlined metal pipes exist, in which internal deposits build up, as a result of mineral deposits or chemical reactions in the water (Walski *et al.*, 2001). This build-up, may result in a loss in the hydraulic capacity of these pipes and may lead to water quality risks due to increasing head loss and disinfectant depletion. Water utilities have the options of cleaning and relining the pipe, replacing the pipe, or placing an additional pipe in parallel with the problematic one. For any of the above mentioned rehabilitation strategies, a model can be used to simulate the behaviour of the pipe under each solution (De Klerk, 2016). As mentioned by Sinske *et al.* (2009), the combination of rehabilitation programmes with other required infrastructure programmes, such as master planning, is an efficient way of ensuring that upgrades and replacements are planned and implemented in an efficient and cost effective way.

3.3.3 Water quality investigations

Apart from the normal water modeling capabilities of hydraulic simulations, some packages provide the functionality to model water quality within a system. Water age, source tracing and constituent concentration analyses can be determined throughout a system. These models can also be used to study hydraulic operations for the improvement of water quality (Walski *et al.*, 2001).

3.3.4 Daily operations

A water distribution system can be used to simulate the daily operations of a system. Typical operations such as the closure of a valve or turning on of a pump can be simulated to obtain the necessary information on what effects these operations will have on a system. Other operating characteristics such as pressures, flows, and tank water levels can also be monitored (Walski *et al.*, 2001). Functionality like this enables the operator to make informed decisions on the adjustment of the system to operate at an appropriate level of service. In addition, a hydraulic simulation can also be used to troubleshoot the system for possible mistakes made by the operator (Newbold, 2009).

3.3.5 Fire protection studies

Water distribution systems are often needed for the provision of water during emergency situations such as fires. As the correct design of a system is essential in order to meet fire protection requirements, conducting a hydraulic modeling analysis on its abilities to meet those requirements is just as crucial. In cases where the system does not provide the required flows and pressures stipulated by an engineer, a model can also be used for the sizing of hydraulic elements in such a way as to improve the system (Walski *et al.*, 2001).

4. Collection and processing of data

4.1 Data collection process

The first step that has to be taken before any data can be collected, is identifying a research area, which in the case of this study, was the LCH area of Kleinmond in the Western Cape Province, South Africa. The following step is to install smart meter loggers at the identified research houses. Smart meter loggers are used in conjunction with each house water meter for measuring water use at certain time intervals. Most of these logger intervals are user defined and loggers can be programmed to measure and record accordingly. Due to the fact that the recorded data that was used for the purposes of this study was retrieved from a web based remote monitoring system from a previous study on LCH by Jacobs *et al.* (2013), the installation and programming of the smart meter loggers were not necessary for this study.

Generally, remotely recorded data can be retrieved on a daily, weekly, or monthly basis, either by using a wireless connection and receiving it via email, or by periodically collecting data from installed loggers. Collected data is then stored in a database. The web based remote monitoring system is discussed in more detail in §4.2.

4.2 Web-based remote monitoring

MyCity is a web based remote monitoring system which gives access to data parameters such as flow, level, pressure, or other fluid characteristics. These data parameters are recorded using a MyCity GSM (Global System for Mobile Communications) Data Logger or other RTUs (Remote Terminal Units) in conjunction with primary measuring instruments. Recorded data is then transferred to the MyCity server by means of the GSM network. The MyCity server can be accessed through a website on which data can be accessed in the form of graphs, tables, or as downloaded csv files.

In a previous Kleinmond LCH study by Jacobs *et al.* (2013), 20 homes were identified where water use was recorded. The actual addresses of houses in the study sample were replaced by hypothetical numbers for the purpose of this investigation in order to protect consumer confidentiality. Jacobs *et al.* (2013) reported a plot size of approximately 40 m^2, with an average household size of 3.9 PPH. The highest occupation obtained was 7 PPH. A summary of the 20 LCH units with the given house number, logger number and number of occupants of each, is given in Table 4.1 (the number H01 was not used simply because the first logger serial number was H02). A summary of the start and end dates of recordings is given in Table 4.2, as well as the number of days on which at least one none-zero reading was taken.

Table 4.1: Household size of Kleinmond study sample (Jacobs et al., 2013)

House number	Household size (PPH)	House number	Household size (PPH)
H02	5	H12	3
H03	3	H13	3
H04	3	H14	4
H05	4	H15	7
H06	2	H16	2
H07	4	H17	4
H08	1	H18	5
H09	4	H19	4
H10	6	H20	3
H11	5	H21	5

Table 4.2: Summary of the research data set recorded

House number	Start date	End date	Days	No. of 15-minute intervals recorded
H02	28/09/2012	16/02/2016	1053	101088
H03	28/09/2012	16/02/2016	1228	117888
H04	28/09/2012	16/02/2016	1236	118656
H05	28/09/2012	16/02/2016	648	62208
H06	28/09/2012	16/02/2016	810	77760
H07	28/09/2012	16/02/2016	1081	103776
H08	28/09/2012	25/04/2014	313	30048
H09	28/09/2012	26/11/2014	790	75840
H10	28/09/2012	03/03/2015	50	4800
H11	28/09/2012	16/02/2016	205	19680
H12	28/09/2012	12/04/2015	901	86496
H13	28/09/2012	08/10/2014	613	58848
H14	28/09/2012	01/01/2016	861	82656
H15	28/09/2012	15/07/2013	0	0
H16	28/09/2012	16/02/2016	139	13344
H17	28/09/2012	03/11/2014	6	576
H18	28/09/2012	31/12/2013	203	19488
H19	28/09/2012	07/07/2013	281	26976
H20	28/09/2012	18/11/2015	867	83232
H21	28/09/2012	27/06/2013	273	26208
Total			11558	1109568

4.3 Extraction of data from MyCity

The flow records of all 20 houses were extracted from the MyCity website. The data was downloaded in February 2016. All recorded data on each house up to February 2016 was therefore included in this study. Each record contained a house number, water logger number, and the measured flow rate, together with the corresponding times and dates of measurement. The recording period interval for this study was 15-minutes, allowing analysis of peak daily flows.

4.4 Data sorting and filtering

The recorded data had several defects that were repeatedly observed. Most of the loggers had the fault of either skipping a single random reading, or taking a duplicate reading within seconds of each other. In addition, several cases in which a number of consecutive data readings were missing, were observed.

A filtering process was carried out by means of a macro function in Microsoft Excel to ensure that duplicates were removed and gaps in the data could be addressed. A detailed explanation of the correction of the data defects is given in §4.5. The schematic presentation of the data sorting, filtering and filling process is also given in Figure 4.1.

4.5 Data filling

4.5.1 Missing 15-minute intervals

On the occurrence of a single missing data reading, the adjacent 15-minute readings were examined. In cases where the adjacent 15-minute intervals were zero (specifically referring to the previous and following readings), the missing value was assigned a value of zero. However, in cases where the previous and/or following reading had non-zero values, an average value between the previous and following value was assigned to the missing value. The missing 15-minute interval readings which had to be filled with an assigned value were recorded for each house and are included in Appendix A.

4.5.2 Extra 15-minute intervals

Some loggers recorded an extra reading at 4 to 5 seconds after the scheduled 15-minute reading. The first captured reading, which was taken at the scheduled 15-minute interval, was used for analysis in the study. The extra unscheduled readings were considered invalid and were deleted. The extra 15-minute interval readings which had to be removed from the data log were recorded for each house and are included in Appendix B.

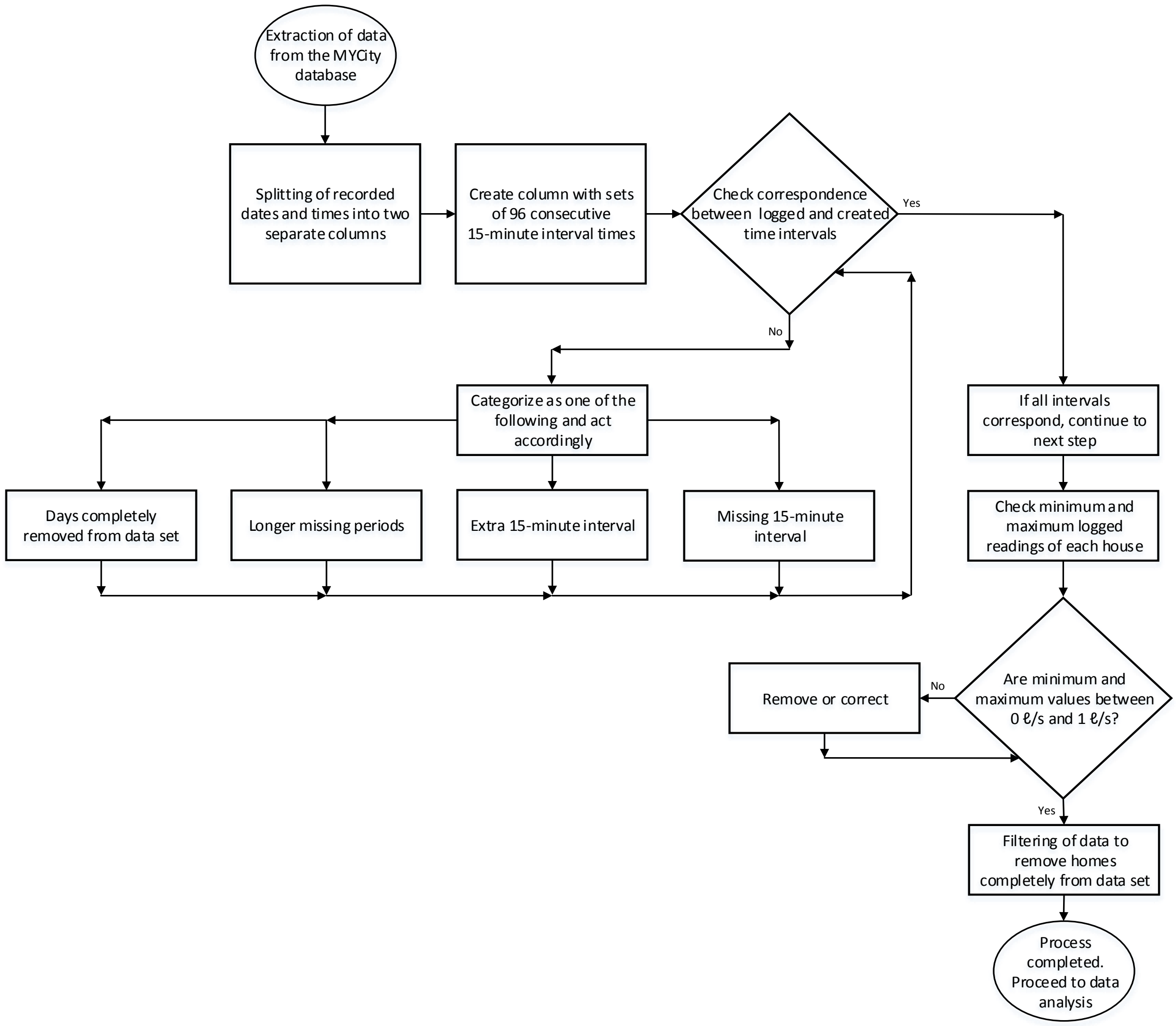

Figure 4.1: Schematic presentation of data sorting and filtering process

4.5.3 Longer missing periods

In some sets of the data, longer periods of consecutive readings were missing. In order to meet the objectives of this study, whole days of records were needed, starting and ending at midnight. Periods of more than 2.5 hours of missing data, meaning 10 consecutive missing readings on a single day, resulted in the whole day being eliminated. For missing periods that stretched over more than one day, the rest of the days on which the missing period had started and finished would be eliminated, except for cases in which the start or finishing days had less than 10 consecutive missing readings, which would then have been treated in the same manner as in §4.5.1.

The following scenario can be taken as an example. If the missing period were from 05/02/2014 15:30 to 07/02/2014 09:45, this means that the last reading taken before the recordings stopped was on 05/02/2014 at 15:15 and that the first reading captured after the missing period was on 07/02/2014 at 10:00. In this scenario, the data readings on the 05/02/2014 and 07/02/2014 would be eliminated. No data would be available for 06/02/2014 in this case. The dates of days removed in this manner are listed in Appendix C.

4.5.4 Minimum and maximum values contained in the data set

The last step that had to be completed before the data was ready for analysis, was to check for minimum and maximum recorded water readings. As discussed in §2.2.3, water meters perform optimally within a certain range of flows. Any readings above or below this range can therefore not be trusted as accurate data.

The recorded flow readings from each house were thus checked for an average rate over 15 minutes between the range of 0 ℓ/s and 1 ℓ/s. The lower limit of 0 ℓ/s was chosen due to the fact that water meters should not record negative readings. The upper limit was based on Van Zyl (2011), which states that multijet water meters with a meter size of 15-25 mm are typically used on small houses. Assuming that 20 mm multijet water meters were used for the houses considered, an upper limit of approximately 1 ℓ/s was used. During this test, no value smaller than 0 ℓ/s was obtained. However, houses H02 and H20 had a maximum value of 1.5 ℓ/s and 2.6 ℓ/s respectively, which was considered too high, in accordance with the above mentioned range. The two invalid maximum values were, therefore, changed to the average recorded value in its applicable set of data, calculated without the maximum value. The average values for houses H02 and H20 were calculated as 0.442 ℓ/s and 0.916 ℓ/s respectively. The minimum and maximum values for each of the 20 Kleinmond houses studied are given in Table 4.3. The second highest values of houses H02 and H20 were used as the maximum values (excluding the invalid maximum values).

Table 4.3: Minimum and maximum recorded water readings for all Kleinmond houses

House number	Minimum value (ℓ/s)	Maximum value (ℓ/s)	House number	Minimum value (ℓ/s)	Maximum value (ℓ/s)
H02	0	0.442	H12	0	0.288
H03	0	0.207	H13	0	0.788
H04	0	0.325	H14	0	0.393
H05	0	0.249	H15	0	0.000
H06	0	0.306	H16	0	0.212
H07	0	0.365	H17	0	0.004
H08	0	0.256	H18	0	0.293
H09	0	0.423	H19	0	0.322
H10	0	0.475	H20	0	0.240
H11	0	0.655	H21	0	0.256

4.6 Summary of filtered data

Each of the 20 Kleinmond houses was analysed separately. However, for the purposes of this study, six houses were excluded due to the lack of sufficient information. The following patterns were thus built for the remaining 14 houses:

- Average diurnal water use pattern, calculated over all seven days of the week.
- Average diurnal weekday and weekend water use patterns.
- Average winter and summer water use patterns.

A decision was made that houses with fewer than 250 recorded days were to be excluded from the study. This can be justified by the fact that houses with less than 250 days were recorded mostly in either the summer or the winter. In these cases, seasonal patterns could be developed for either only winter or only summer, and could not have been compared to the opposite seasonal pattern. The study area is characterised by relatively hot, dry summers and cold, wet winters. Summer season was considered to include months from September to February and winter from March to August.

Table 4.4: Summary of the houses used for the analysis of diurnal patterns

House number	Days	Weekdays	Weekends	Summer	Winter	Included	Excluded
H02	1053	748	305	533	520	X	
H03	1228	879	349	678	550	X	
H04	1236	882	354	685	551	X	
H05	648	462	186	293	355	X	
H06	810	581	229	468	342	X	
H07	1081	773	308	547	534	X	
H08	313	223	90	150	163	X	
H09	790	564	226	422	368	X	
H10	50	36	14	50	0		X
H11	205	148	57	146	59		X
H12	901	649	252	496	405	X	
H13	613	439	174	284	329	X	
H14	861	616	245	477	384	X	
H15	0	0	0	0	0		X
H16	139	99	40	139	0		X
H17	6	3	3	0	0		X
H18	203	148	55	154	49		X
H19	281	200	81	153	128	X	
H20	867	620	247	500	367	X	
H21	273	195	78	154	119	X	

Table 4.4 shows that houses H10, H11, H15, H16, H17 were recorded for fewer than 250 days (Column 2). Weekdays and weekend days, as well as the summer and winter days, were also included in Table 4.4. As can be seen, all the houses excluded had very few or no days recorded in either the winter or the summer.

All the processing of the data was done by means of programmed macro functions in Microsoft Excel to speed up the data analysis process. The macro functions were validated by examining whether the number of days on which data was recorded per house corresponded with the sum of the weekdays and weekend days on which data was recorded per house. The same process was followed with the summation of summer and winter days. As can be seen in Table 4.4, this was the case for all considered houses.

5. Data analysis

5.1 Diurnal patterns

5.1.1 Average diurnal patterns

The following steps were followed in the process of obtaining an average diurnal water use pattern for each house considered. A brief overview is given on each of these steps.

- Calculate a set of 96 values containing the totals for each 15-minute period per day over the total number of days that water use was recorded.
- Calculate the total number of days on which water use was recorded.
- Calculate the average flow consumed for each 15-minute interval per day.
- Plot the average daily flows (y-axis) for each 15-minute period (x-axis) per day.

An average diurnal pattern was created for each house over the total number of days recorded. Since each day has a total of 96 intervals over the 24 hours, a set of 96 values was obtained in the process of adding the recorded data readings at their corresponding 15-minute interval times. This set of data represented the total flows per 15-minute interval over a period of 24 hours.

The total number of days on which water use was recorded was needed in order to calculate the average flow. It was assumed that for each day (starting at the 00:00 interval and ending at 23:45), at least one non-zero reading should be available. Any day with 96 consecutive zero readings would therefore not have been counted.

The average water use per 15-minute interval was calculated by dividing each of the 96 interval totals by the total number of days obtained. The diurnal pattern was then constructed by plotting these average 15-minute interval values.

Soon after constructing a diurnal water use pattern for all of the 14 houses considered, a general diurnal water use pattern was constructed to represent the global diurnal water use pattern for LCH units. The development of this last pattern was done by the calculation of a weighted average pattern, using the data obtained for all houses. A weighted average is defined as an average resulting from the multiplication of each component by a factor reflecting its component. In this study, each house was considered as a component from which the factor of importance was considered to be the number of days on which at least one non-zero value was recorded. Equation 2 was used for the calculation of the weighted average on each of the 96 intervals per day.

$$(\overline{Q}) = \frac{\sum_{i=1}^{n}(Q_{T_i} \times D_{T_i})}{\sum_{i=1}^{n} D_{T_i}}$$

$$(\overline{Q}) = \frac{Q_{T_1} \times D_{T_1} + Q_{T_2} \times D_{T_2} + \dots + Q_{T_{n-1}} \times D_{T_{n-1}} + Q_{T_n} \times D_{T_n}}{D_{T_1} + D_{T_2} + \dots + D_{T_{n-1}} \times D_{T_{n-1}} + D_{T_n} \times D_{T_n}} \qquad (2)$$

where:

$\overline{Q}$ is the weighted average flow;

D_{T_i} is the total number of days on which water was recorded at house i;

Q_{T_i} is the total flow for the particular 15-minute interval at house i; and

n is the total number of houses considered for building a diurnal pattern.

5.1.2 Weekday and weekend diurnal patterns

An important distinction to make regarding diurnal patterns is between weekdays (Monday to Friday) and those of weekend days (Saturday and Sunday). The following steps were followed in the process of obtaining an average diurnal weekday and weekend water use pattern for each house considered. A brief description of each of these steps follows.

- Assign the correct day of the week to each of the dates on which data was recorded. The MS Excel calendar was used in a macro function with the purpose to have automatically assigned the name of the day to each actual reading based on its date.
- Calculate a set of 96 values containing the totals for each 15-minute period per weekday over the total number of weekdays on which water use was recorded.
- Calculate a set of 96 values containing the totals for each 15-minute period per weekend day over the total number of weekend days on which water use was recorded.
- Calculate the total number of weekdays on which water use was recorded.
- Calculate the total number of weekend days on which water use was recorded.
- Calculate the average flow consumed for each 15-minute interval per weekday.
- Calculate the average flow consumed for each 15-minute interval per weekend.
- Plot the average weekday and weekend day flows (y-axis) for each 15-minute period (x-axis) per day.

For the purposes of constructing the week and weekend patterns, the summation of the recorded readings for each respective 15-minute interval was done in the same manner as for the average diurnal patterns. However, two sets (weekday and weekend) of 96 intervals were obtained. The weekday and weekend sets were obtained by the assignment of a day of the week to each of the data points on which readings were taken. Each recorded reading was then added to the corresponding 15-minute interval in either the weekday or weekend set according to the assigned day.

The summation of the total number of weekdays and weekend days was then executed. The average weekday and weekend pattern values were calculated by dividing each of the 96 intervals for weekdays and weekend days by the total number of weekdays and weekend days obtained. The weekday and weekend patterns were then constructed and compared after the calculated average weekday and weekend day values had been plotted on a graph. The procedure described by the bullet list was followed for every house considered.

5.1.3 Summer and winter diurnal patterns

The study area is characterised by relatively hot, dry summers and cold, wet winters. Summer season was considered to include months from September to February and winter from March to August. The following steps were followed in the process of obtaining an average diurnal summer and winter water use pattern for each of the houses.

- Assign a month of the year to each of the 15-minute intervals on which data was recorded.
- Calculate a set of 96 values containing the totals for each 15-minute period per summer day.
- Calculate a set of 96 values containing the totals for each 15-minute period per winter day.
- Calculate the total number of summer days on which water use was recorded.
- Calculate the total number of winter days on which water use was recorded.
- Calculate the average flow consumed for each 15-minute interval per weekday.
- Calculate the average flow consumed for each 15-minute interval per weekend.
- Plot the average summer and winter flows (y-axis) for each 15-minute period (x-axis) per day.

Two sets of data (summer and winter) were obtained after the recorded readings for all respective 15-minute intervals had been summed according to season. In order to obtain a diurnal water use pattern, the summed flow rates for each 15-minute interval had to be divided by the total number of days with recorded data on record.

The total cumulative number of validated days were counted in each season. Each day with at least one non-zero value was added to the total number of either the summer or the winter days, according to the month of the year in which its readings were taken.

The average summer and winter diurnal patterns were obtained by dividing each 15-minute interval in the summer set by the total number of summer days and the same for winter. These two sets of values were calculated and plotted on a graph, and represent the diurnal summer and winter water use patterns for LCH units.

5.2 Peaking factors

PFs were calculated for the 11 houses that had recorded data for a full year, from 1 January to 31 December. Complete sets of data were available for the years of 2013, 2014 and 2015. In the following section, a brief description is given of the calculation of the three types of PFs mentioned earlier.

Since all the datasets consisted of 15-minute interval readings, no changes had to be made for the calculation of 15-minute PFs. However, for the calculation of peak hour factors (PHFs) and peak day factors (PDFs), data had to be aggregated.

After the conversion of the 15-minute interval readings to suitable units, the following PFs were calculated from the corresponding data sets:

- $PF_{15\text{-}min}$ from 15-minute recorded readings.
- PHF from the converted sets of hourly flows.
- PDF from the converted sets of daily flows.

The PFs were calculated by means of Equation 3, for each type over each year for each house:

$$PF = \frac{Maximum\ flow}{Average\ flow} \qquad (3)$$

$PF_{15\text{-}min}$s were calculated from the maximum 15-minute interval reading taken from the complete set of 15-minute interval readings in the year concerned, divided by the average taken over the same set of data. The PHFs and PDFs were calculated similarly by dividing the maximum hourly and daily flows by the average hourly and daily flows respectively.

After calculating the PFs for each house, the respective PFs were also calculated from the combined data of the 11 houses. As mentioned, complete one-year sets of data were available for only the years of 2013, 2014 and 2015. The data from all houses considered therefore needed to be grouped for each of the years in which complete sets of data were available. The number of houses with a complete one-year set of data in each of the above mentioned years were as follows:

- 11 houses for the year of 2013.
- 8 houses for the year of 2014.
- 4 houses for the year of 2015.

After grouping all the complete sets of data in each of the specified years, the $PF_{15\text{-}min}$s, PHFs and PDFs were calculated. The calculations were done in the same manner as discussed for each of the three types of PFs above.

6. Results and discussion

6.1 Diurnal patterns

6.1.1 Minimum night flow verification

During the process of constructing average diurnal water use patterns for each LCH unit, a meticulous investigation was conducted to identify leaks at each house by considering the minimum night flow (MNF) on each house`s diurnal pattern. No traces of any major water losses were found in any of the houses except for house H06. It was assumed that houses with less than 15% losses of the total daily water use were acceptable, since literature showed that unaccounted for water should be less than 15% of the total amount of water metered (refer to §2.2.5.2). Lugoma *et al.* (2012) studied 182 properties in Johannesburg and found an average leakage of about 25% of the measured water use. The allowance of 15% losses in this study therefore seem adequate. All considered houses satisfied the condition, except for house H06.

The data obtained for house H06 was carefully investigated in search of possible leakages. For the purposes of spotting a leakage, all of the 15-minute interval flows per day were summed for the whole set of data on house H06. The summed 15-minute intervals per day are thus expressed in terms of ℓ/s/d. It was decided that all of the recorded days exceeding a total flow of 1 ℓ/s/d would be identified. After identifying the 61 maximum water consuming days exceeding 1 ℓ/s/d, an observation was made regarding the order of the maximum water use dates. After rearranging these dates and placing them in sequence, all of the obtained maximum use dates followed on each other. The set of 61 maximum consuming days existed between 09/02/2014 and 26/05/2014, as can be seen in Table 6.1.

However, a gap of 35 days was found to exist between two of the successive dates in the set of maximum consuming days. At first, a water leakage was suspected to have started on 09/02/2014, which was fixed on 19/02/2014, and was followed by similar water leakage occurring on 26/03/2014. However, this was not the case as all of the recorded data between 20/02/2014 and 25/03/2016 had zero value readings. The identified water losses can therefore be ascribed to one major leakage as the water meter logger did not function correctly during the 35-day gap.

Table 6.1: Identified dates on which major water leakages occurred on house H06

Date	Total flow (ℓ/s/d)	Date	Total flow (ℓ/s/d)	Date	Total flow (ℓ/s/d)
09/02/2014	2.30	05/04/2014	4.59	29/04/2014	8.33
10/02/2014	5.85	07/04/2014	2.49	30/04/2014	5.74
11/02/2014	8.64	08/04/2014	4.18	01/05/2014	6.05
12/02/2014	8.61	09/04/2014	2.78	04/05/2014	2.76
14/02/2014	8.87	10/04/2014	5.14	12/05/2014	5.76
16/02/2014	8.72	11/04/2014	2.86	13/05/2014	5.37
18/02/2014	8.84	14/04/2014	2.27	15/05/2014	8.70
19/02/2014	7.67	15/04/2014	5.70	16/05/2014	8.64
26/03/2014	2.80	16/04/2014	9.38	17/05/2014	8.63
27/03/2014	5.33	17/04/2014	2.99	18/05/2014	8.63
28/03/2014	5.90	20/04/2014	2.33	19/05/2014	8.62
29/03/2014	5.94	21/04/2014	8.79	20/05/2014	8.62
30/03/2014	4.73	22/04/2014	8.84	21/05/2014	8.64
31/03/2014	4.36	23/04/2014	8.81	22/05/2014	8.64
02/04/2014	2.12	24/04/2014	4.87	23/05/2014	3.84
03/04/2014	4.75	25/04/2014	2.78	25/05/2014	3.69
04/04/2014	5.81	28/04/2014	3.59	26/05/2014	2.37

The discovery of one major water leakage on house H06 serves as proof that the subtraction of the MNF had been necessary. As can be seen in Figure 6.1, the subtraction of the MNF led to a significant drop in values for the average diurnal pattern of house H06.

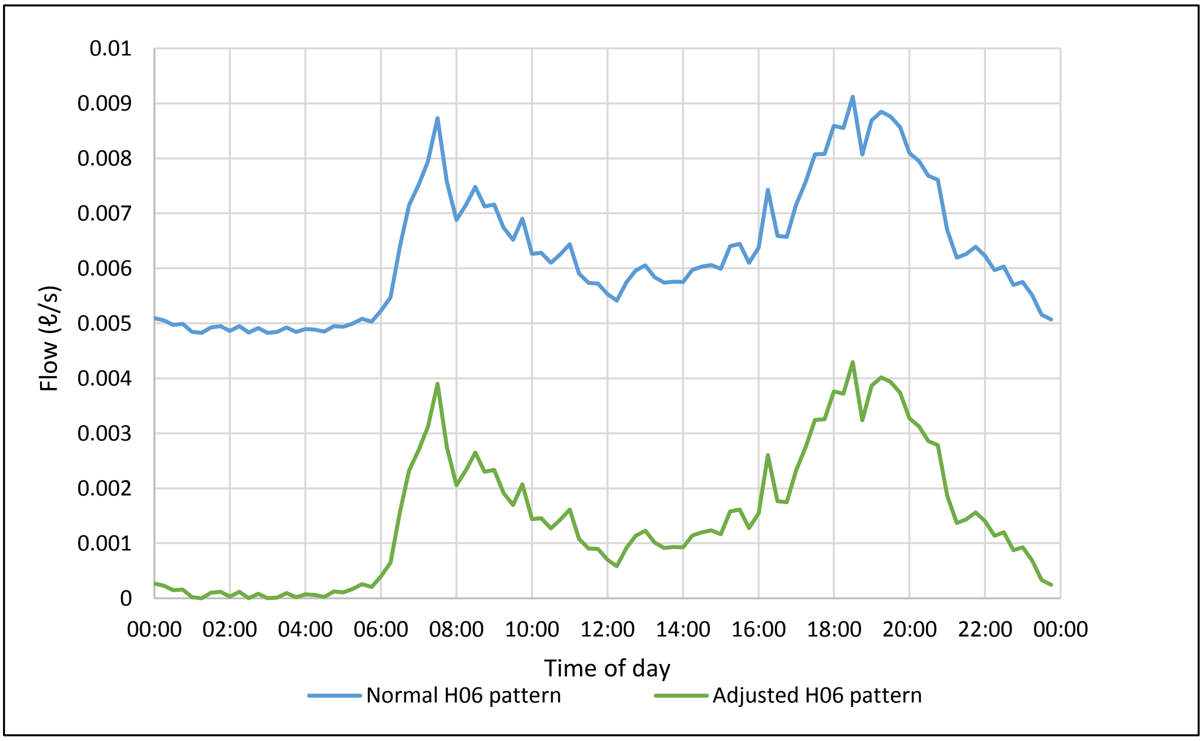

Figure 6.1: Normal vs adapted average diurnal pattern for house H06

The water use pattern for house H06 exhibited a relatively high MNF of 0.0048 ℓ/s, which was 76.8% of the total daily use. The MNF value was deducted from all of the obtained average 15-minute interval values of house H06. The adapted values of H06, excluding MNF, were used in the processes of constructing weekday versus weekend, as well as summer versus winter, diurnal patterns. However, relatively insignificant losses from the houses were included in the construction of the diurnal water use patterns, except for house H06, as discussed. For house H06 a zero MNF value was used.

6.1.2 Average diurnal patterns

Following an investigation into the diurnal water use pattern of LCH units, it was observed that the GLS LCH water use pattern (Compion, 2010) differed significantly from standard residential water use patterns (refer to §2.4.5). All houses were shown to have two water use peaks per day. A weighted average diurnal pattern was derived based on all recorded data obtained. The average diurnal water use patterns, together with the weighted average diurnal pattern, are presented in Figure 6.2.

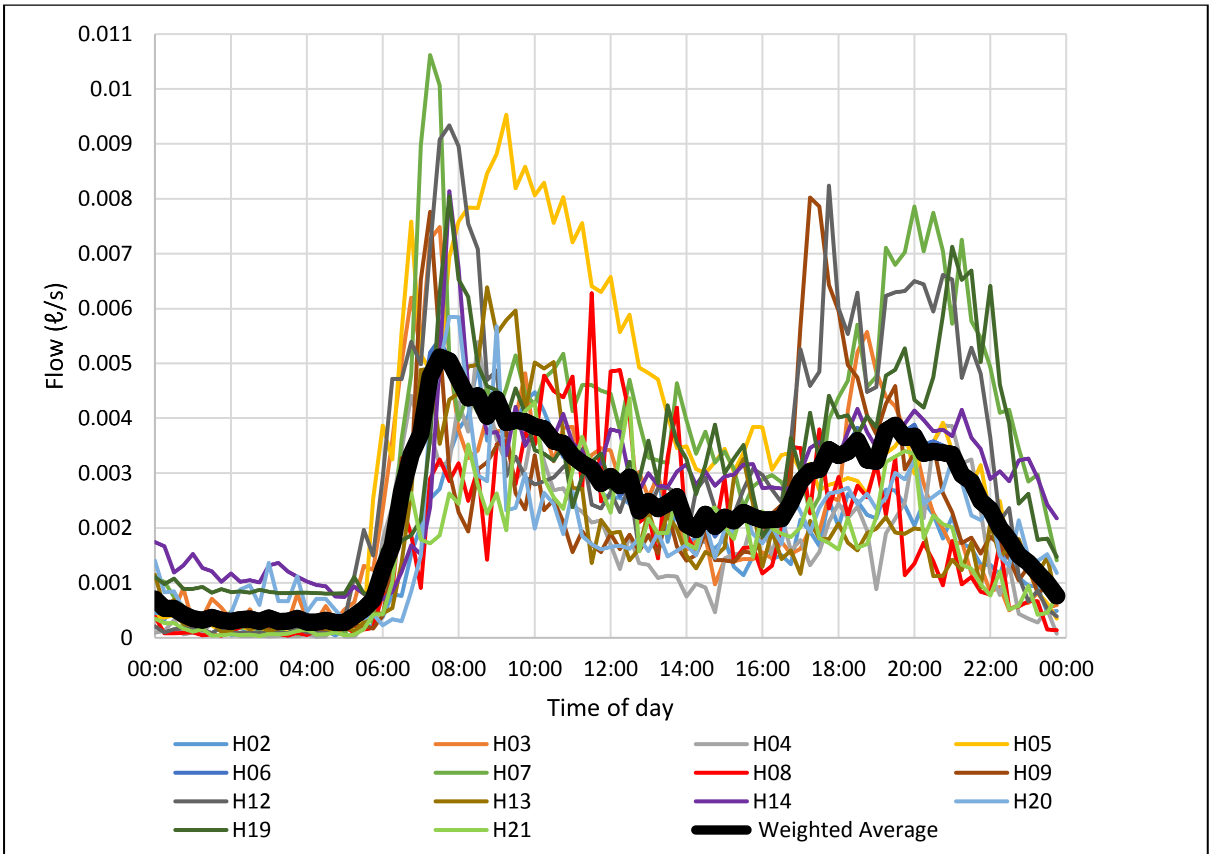

Figure 6.2: Average pattern developed, together with all individual diurnal house patterns

Two distinct water use peaks were observed in both the general diurnal pattern, as well as in all the individual houses` diurnal patterns, representing the morning and evening water use peaks respectively. The morning peak on the average pattern occurred between 05:45 and 07:30, while the evening peak occurred between 16:45 and 19:30. The morning peak was observed to be 30.2% higher than the evening peak over all three years. In addition, the morning peak was also shorter than the evening peak as it lasted for 1 hour and 45 minutes, compared to a longer-lasting evening peak of 2 hours and 45 minutes. A possible reason for this observation is the fact that working occupants rush to get to work in the morning whereas, in the evening, circumstances are a little more relaxed. Water is therefore used over a shorter period in the morning. The above-mentioned characteristics significantly correspond to the standard characteristics of residential water use patterns.

6.1.3 Average weekday and weekend diurnal patterns

The average weekday and weekend diurnal water use patterns were found to be similar in shape and size to the average diurnal water use pattern, as can be seen in Figure 6.3.

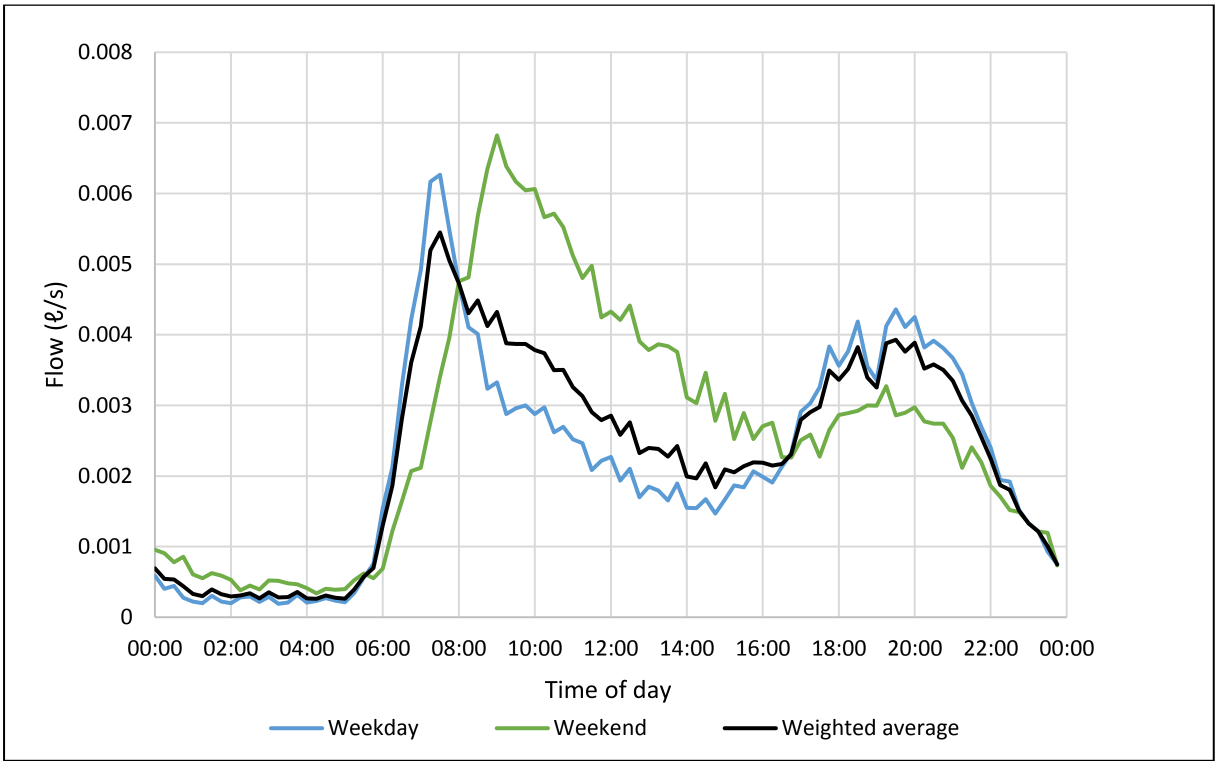

Figure 6.3: Comparison between average diurnal weekday and weekend water use patterns

The weekday morning peak were observed to be lower than the weekend morning peak, but the weekday evening peak was higher than the weekend evening peak. Furthermore, the duration of the weekday morning peak was shorter than the weekend morning peak, as could be expected.

The weekday morning peak occurred between 05:45 and 07:30, whereas the corresponding times for the weekend morning peak was 06:00 and 09:00. For the evening peaks, both the weekday and weekend peaks occurred between 16:15 and 19:30.

6.1.4 Average summer and winter diurnal patterns

The summer and winter average diurnal water use patterns, were similar in size and shape, as can be seen in Figure 6.4. Since LCH property sizes are relatively small, houses occupy the biggest part of the property, leaving limited space for privileges such as swimming pools and large irrigated gardens. All houses in the study sample had rainwater harvesting tanks, which were installed during initial construction. Since the Western Cape is a winter rainfall region water from rainwater tanks would typically not be available during the hot and dry summer months. The absence of outdoor use is a feasible explanation for the similarity between the winter and summer diurnal patterns.

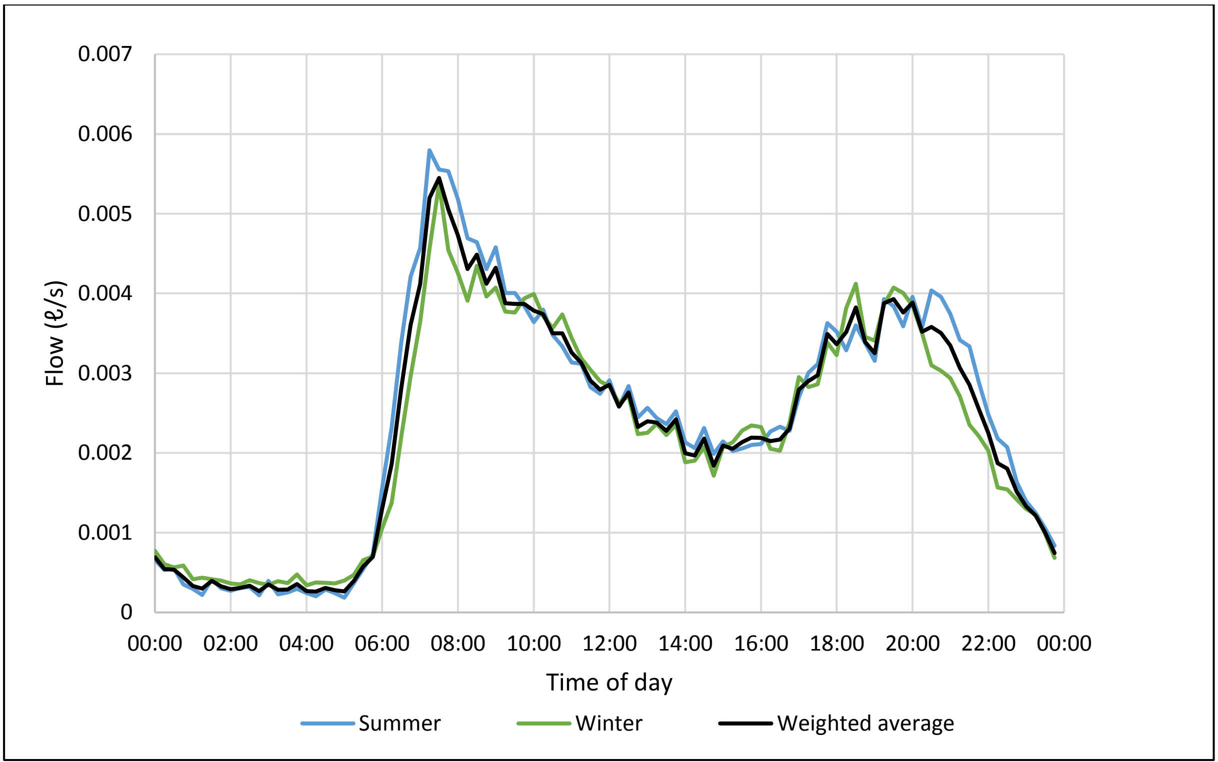

Figure 6.4: Comparison between average diurnal summer and winter water use patterns

6.1.5 Dimensionless 24-hour pattern

An average dimensionless 24-hour pattern was derived for all LCH units and days in the study sample, thus including all days of the week (weekdays and weekend days) and all days in the year (summer and winter). The calculated hourly factors are given in Table 6.2 and the pattern is presented in Figure 6.5. The values are expressed as multiplier factors. The multiplier factors were obtained by dividing each of the calculated hourly flows from the weighted average pattern (refer to Figure 6.2) by the average hourly flow. The actual peak flow pattern can be obtained by multiplying the ADD of a house (or housing area) by the ordinates of the dimensionless graph.

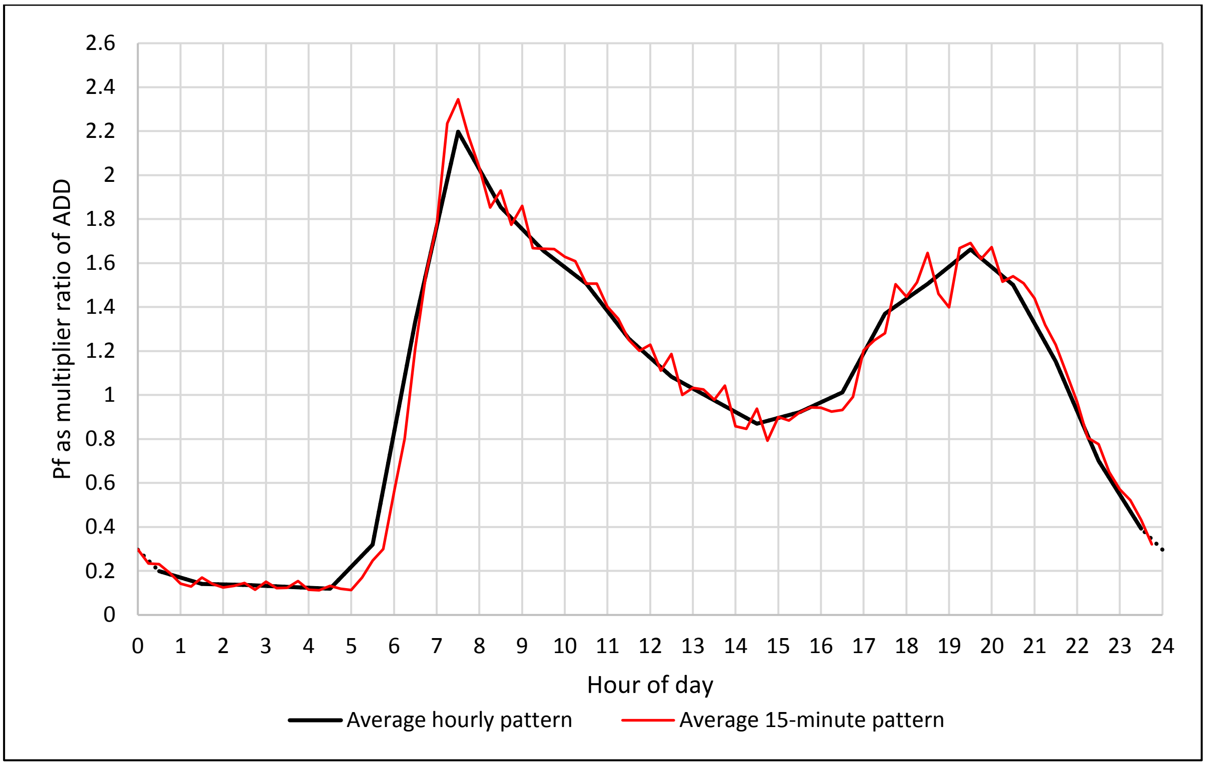

Figure 6.5: The dimensionless 24-hour pattern generated for LCH units

Table 6.2: Calculated PHFs for each hour of the day

Hour of day	Multiplier factors	Hour of day	Multiplier factors
00:30	0.199	12:30	1.083
01:30	0.141	13:30	0.976
02:30	0.136	14:30	0.869
03:30	0.128	15:30	0.923
04:30	0.119	16:30	1.013
05:30	0.319	17:30	1.370
06:30	1.334	18:30	1.505
07:30	2.197	19:30	1.663
08:30	1.855	20:30	1.501
09:30	1.657	21:30	1.154
10:30	1.506	22:30	0.701
11:30	1.257	23:30	0.393

The 15-minute PF values for the average diurnal pattern are superimposed on the hourly factors graph in Figure 6.5. The 15-minute PF values for the average diurnal pattern, average weekday pattern, as well as the average weekend pattern are given in Appendix D. The 15-minute PF values for the average summer and winter patterns are not included due to the fact that the patterns are similar to the average diurnal pattern (refer to §6.1.4).

The hourly pattern, with 24 PF values instead of a 15-minute pattern with 96 PF values, is useful in cases where software only allows for the input of 24 values (some commercial software products allow for a higher resolution). By reducing the resolution on the time axis from 15-minute to 1-hour, the maximum PF reduces from $PF_{15\text{-}min}$= 2.34 to PHF = 2.20.

The timing of the hourly factors can be explained with the use of an example. Considering the peak hour between 07:00 and 08:00, an hourly flow was obtained by taking the average of the flows at 07:15, 07:30, 07:45 and 08:00. The plotting position for the average of the four PF values was at 07:30 on the time axis. The timing of the hourly factor at 07:30 corresponds to timing of the 15-minute peak.

The sum of the PF values in Table 6.2 is 24, due to the fact that the ratios over 24 hours are dimensionless. The PFs are dimensionless due to the fact that the hourly factors were calculated by dividing each of the 24 hourly flows by the average of the same set of 24 hourly flows.

6.2 Discussion – Diurnal pattern

The newly generated hourly PF pattern was compared to the hourly PF pattern presented by Compion (2010) in Figure 6.6. The two patterns differ significantly. The original pattern (Compion, 2010) has only one peak per day, with a PF of 1.6. The newly developed pattern, however, appears to be very similar in shape to standard residential diurnal patterns (refer to §2.4.5). The pattern derived during this research study shows a distinct peak occurring in both the morning and evening. The morning and evening peaks of the derived pattern have PFs of 2.197 and 1.663, respectively. Both peaks of the newly developed pattern are higher than the single peak of the former pattern. Since the single peak presented by Compion (2010) is much smaller, it lasts longer than the peaks from the newly developed pattern, because the integral of each curve is equal to 24. The demand pattern presented by Compion (2010) is used by GLS Consulting for EPS and is referred to as the 'GLS-pattern' in the remainder of this text.

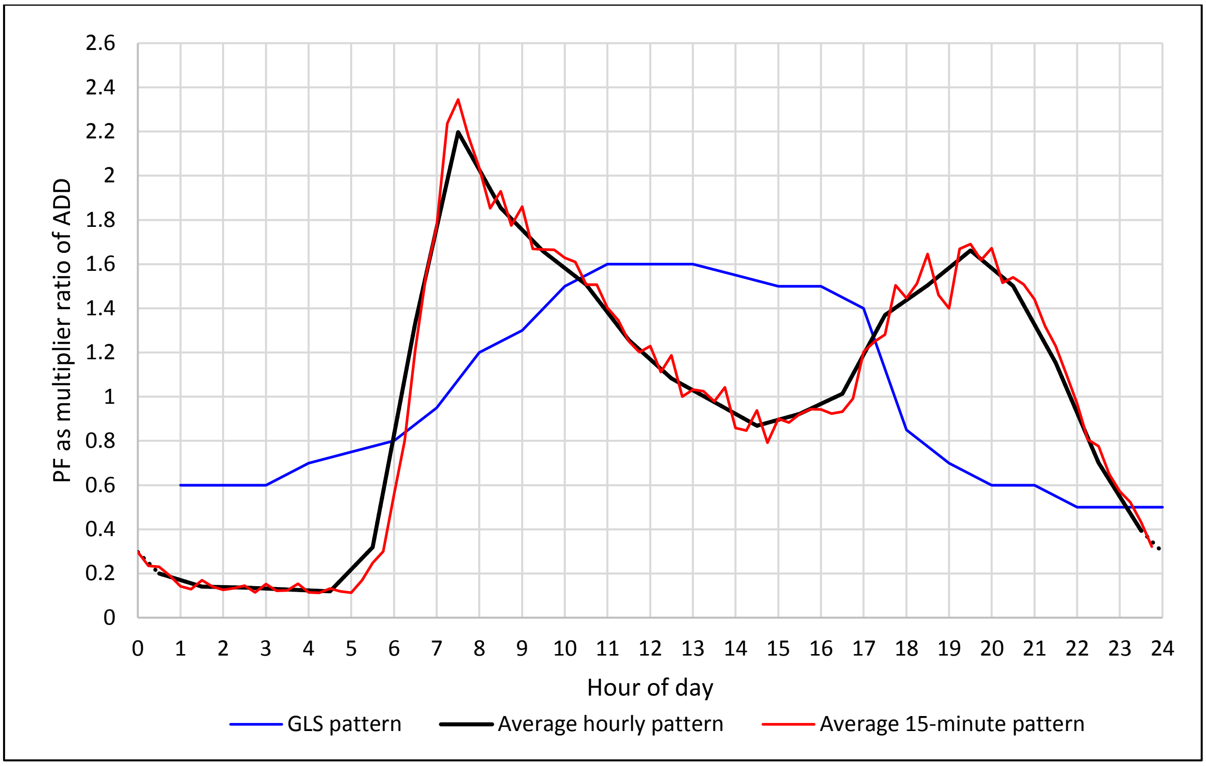

Figure 6.6: Comparison of water use patterns

6.3 Peaking factors

Three types of PFs were calculated from the data obtained from 11 separate LCH units for 2013, 2014 and 2015. The calculated PFs calculated are tabulated in Table 6.3. All PFs are based on AADD, meaning that the $PF_{15\text{-}min}$s were the highest in value, with an average of 117.25, followed by the PHFs at 50.16 and PDFs with an average of 6.31. As can be noted, PFs decreased with the increase in the associated δt, as could be expected. The maximum and average values obtained for the calculation of all three types of PFs, together with the corresponding calculated PFs, are given in Appendix E.

After calculating PFs for individual consumers, PFs were also calculated from the combined data in 2013, 2014 and 2015 for small groups of houses. As can be seen in Table 6.4, all 11 houses used for derivation of the diurnal patterns earlier had complete one-year sets of data for the year of 2013, whereas 8 houses had complete sets for 2014 and 4 houses for 2015. Similar to the concept of PFs being highly related to δt, PFs are also related to the number of consumers in the affected area of the water distribution system. PFs generally decrease with an increase in the number of consumers, because the variability of water use patterns decreases due to attenuation.

Table 6.3: Calculated PFs for each of the 11 houses considered

Number	House number	Year	$PF_{15\text{-}min}$	PHF	PDF
1	H02	2013	202.7	51.3	2.9
	H02	2014	185.1	46.6	4.1
	H02	2015	201.0	81.0	6.4
2	H03	2013	94.4	60.1	6.6
	H03	2014	75.1	30.3	5.2
	H03	2015	88.8	42.9	5.5
3	H04	2013	160.5	84.6	9.6
	H04	2014	151.7	63.8	10.4
	H04	2015	187.8	157.0	14.9
4	H05	2013	63.6	29.5	2.9
	H05	2014	68.5	17.5	2.9
5	H06	2013	26.4	20.1	8.6
6	H07	2013	84.6	50.7	3.8
	H07	2014	97.7	42.9	5.1
	H07	2015	104.3	38.0	4.0
7	H09	2013	130.3	38.8	4.4
8	H12	2013	81.6	40.1	6.7
	H12	2014	93.4	37.1	4.2
9	H13	2013	157.4	40.5	2.7
10	H14	2013	49.4	24.2	6.9
	H14	2014	59.9	55.7	12.8
	H14	2015	159.7	42.9	2.6
11	H20	2013	140.5	45.2	8.0
	H20	2014	149.8	63.0	10.5
Average			117.3	50.2	6.3
Average plotted as No of households = 1 on Figures:			Figure 6.7	Figure 6.8	Figure 6.9

Table 6.4: Calculated PFs from the combined data of a number of consumers

Year	Houses available	$PF_{15\text{-}min}$	PHF	PDF
2013	11	40.2	11.0	2.0
2014	8	27.4	13.4	2.8
2015	4	47.4	29.5	4.3

A decrease in PFs with the increase in the number of consumers was observed in all three types of PFs calculated, except for the step from the PF calculated for 8 houses (27.42) to the PF calculated for 11 houses (40.16) in the $PF_{15\text{-}min}$ group. The decrease in PFs with the increase in the number of consumers is more evident in the visual presentation of the PFs, as all calculated PFs were grouped and plotted on Figure 6.7 ($PF_{15\text{-}min}$s), Figure 6.8 (PHFs) and Figure 6.9 (PDFs). In the above mentioned figures, blue dots represent PFs calculated on individual households in the years of 2013, 2014 and 2015 (number of households = 1 on the x-axis). The average of the blue dotted single number of households were plotted as a black dot, with the purpose of constructing a curve line. The following number of households were available:

- 11 number of households in the year of 2013, plotted as an orange dot.
- 8 number of households in the year of 2014, plotted as a grey dot.
- 4 number of households in the year of 2015, plotted as a green dot.

The combination of all three types of calculated PFs are summarized in Figure 6.10.

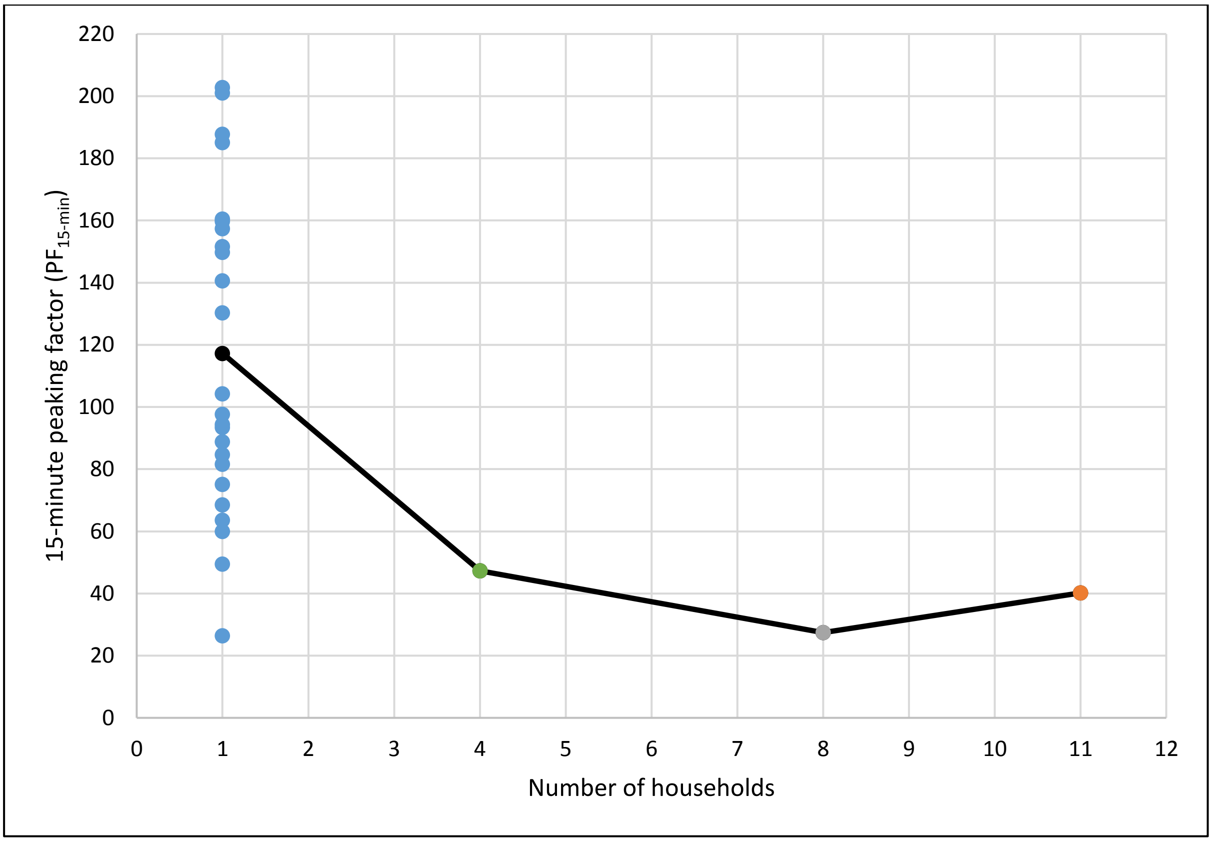

Figure 6.7: All calculated 15-minute peaking factors

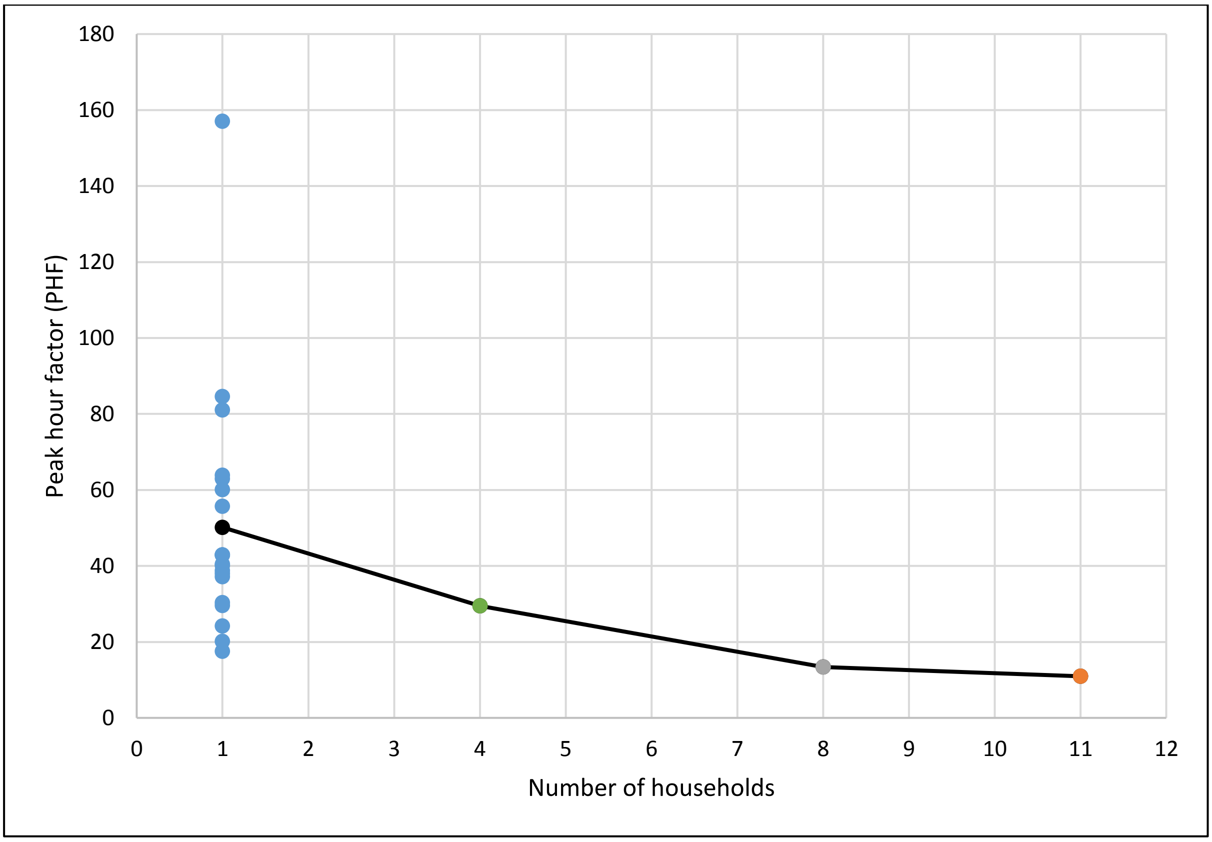

Figure 6.8: All calculated peak hour factors

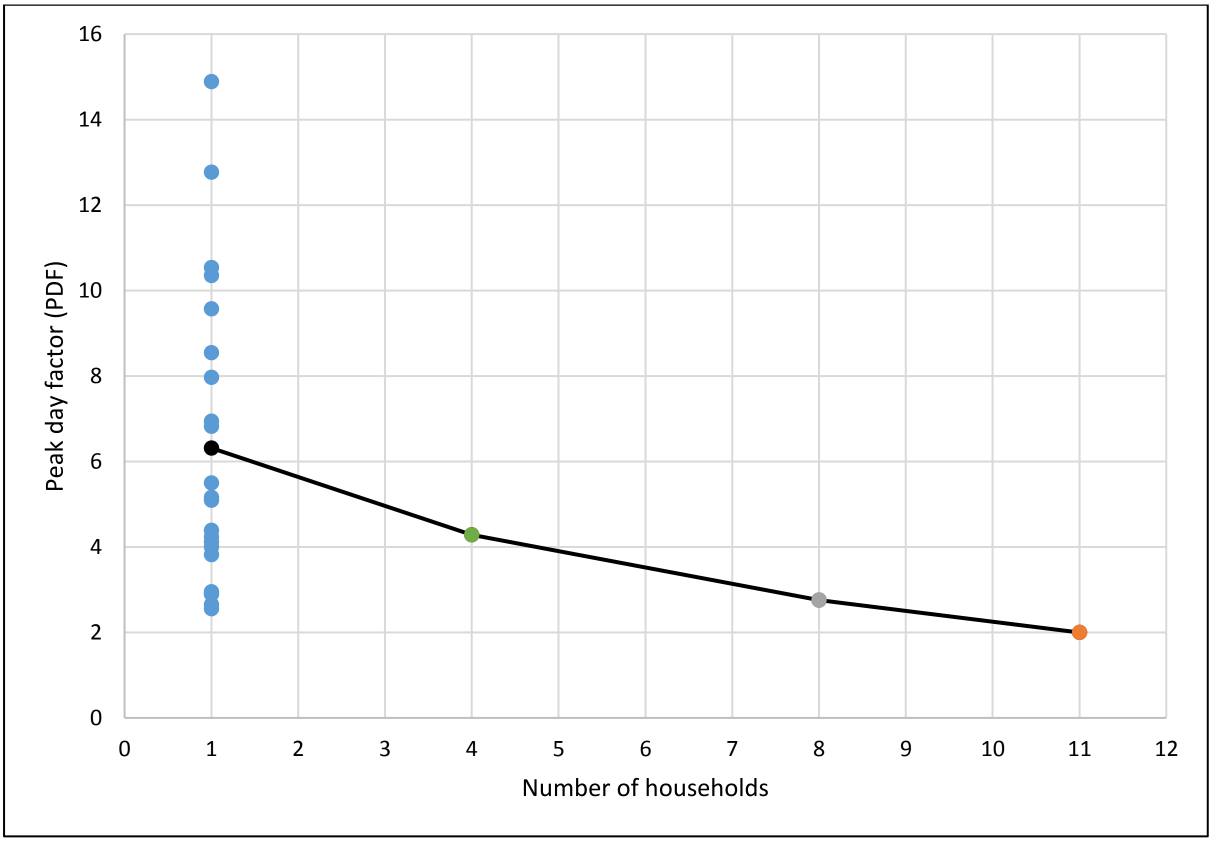

Figure 6.9: All calculated peak day factors

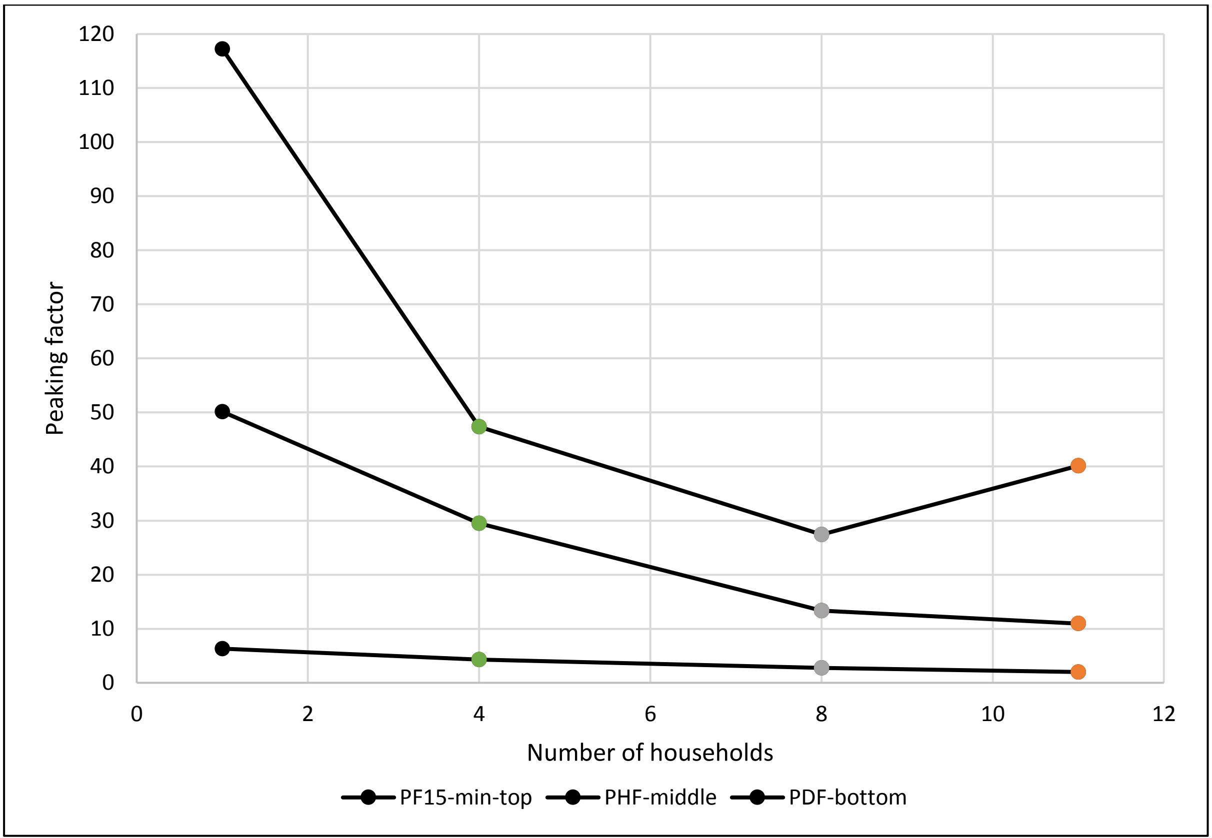

Figure 6.10: All of the 15-minute, hourly and daily peaking factors calculated

The PFs calculated from this study were compared to the PFs found in the study by Scheepers (2012) and the CSIR (2003) (refer to §2.5.2). Differences ranged between 47% and 80%, and could be ascribed to the fact that Scheepers (2012) used data from a completely different residential consumer type, from North America. The outdated CSIR (2003) PFs are notably lower than the results from this study. The study sample in this research exclusively contained LCH consumers, with results based on actual data that has not been available previously. The consumer type clearly plays an important role in deriving PFs.

Table 6.5: Difference in peaking factors between this study, Scheepers (2012) and CSIR (2003)

No of households	PF15-min		PHF		Instantaneous PF
	This study	Scheepers (2012)	This study	Scheepers (2012)	CSIR (2003)
1	117.25	62.2	50.2	17.9	18
4	47.35	16.4	29.5	8.0	16
8	27.42	10.9	13.4	4.3	14
11	40.16	7.8	11.0	4.3	13

7. Conclusions

7.1 Key findings

The constant need for infrastructure development and potable water services, as a result of the expansion of urban areas, has highlighted the importance of accurate estimates of water demand in the planning and design of municipal water services. Inadequate estimates lead to a deficiency in basic design information that could lead to inadequate water service provision. The estimation of present water demand, as well as the prediction of future water demand is therefore one of the key inputs in municipal water services planning and design.

Various studies were reviewed for an in depth understanding of the diurnal water use patterns and the derivation of PFs. Six of the seven water use studies reviewed as part of this research into water use on residential areas were reported to have two distinct water use peaks per day. Compion (2010) reported only one diurnal peak, but the work by Compion (2010) was unique in addressing LCH in particular.

As part of this study, water use for 20 LCH units, recorded every 15 minutes for about 3 years, was accessed via an online reporting system. The downloaded data was organised and filtered to obtain a data set suitable for further analysis. Macro functions were programmed in Microsoft Excel for the development of an empirically derived LCH water use pattern. In addition, weekday versus weekend, as well summer versus winter water use patterns were also developed. The developed LCH pattern differed significantly from the only available diurnal pattern for LCH units (Compion, 2010).

The diurnal water use patterns were also used for the calculation of PFs. Peak 15-minute, hourly and daily PFs were calculated for 11 households. The PFs from this study were relatively higher than work by Scheepers (2012). The PFs from this study were also notably different from the PFs provided by CSIR (2003). However, the consumer types from Scheepers (2012) and CSIR (2003) were significantly different from the LCH consumer type considered in this study.

PFs reported by Scheepers (2012) and CSIR (2003) were notably lower than the results from this study. The study sample in this research exclusively contained LCH consumers, with results based on actual data that has not been available previously. The consumer type therefore probably impacts on diurnal water use patterns and PFs.

7.2 Discussion

Two distinct peaks occur in the diurnal water use pattern developed during this study, one each in the morning and evening. The morning peak occurred between 05:45 and 07:30, while the evening peak occurred between 16:45 and 19:30. The morning peak was observed to be significantly higher and more pronounced than the evening peak. The morning peak was shorter than the evening peak, lasting for 1 hour and 45 minutes, compared to 2 hours and 45 minutes in the evening. The shorter morning peak can be ascribed to the fact that working occupants rush to get to work in the morning, whereas in the evening, circumstances are a little more relaxed.

The dimensionless 24-hour pattern developed enables water demand planners to predict the water use pattern for any similar LCH area with a known AADD. The dimensionless pattern consists of PHFs which can be multiplied by the AADD to obtain the actual water use. The morning and evening peaks have a PF of 2.197 and 1.663 respectively. Furthermore, the weekday morning peaks were of a shorter duration than the weekend morning peaks. The summer and winter water use patterns were similar in size and shape.

A relationship was found between the magnitude of the PFs and the time interval over which the PF was calculated, δt. As found in the literature, PFs in other studies were related to the interval δt. The literature shows that PFs increase as δt decreases, which was also the case in this study. In addition, PFs were reported to be related to the number of households in the water supply zone. As the number of consumers increased, the PFs decreased. The reason for this phenomenon is the fact that the variability of water use decreases with an increase in the number of households.

This study produced novel diurnal water use patterns and PFs for LCH that could be used for future steady state analysis of water distribution systems, as well as for time simulations. The newly developed patterns and PFs differ notably from previously reported values, especially in terms of the timing of daily peaks. The results agree with the general characteristics of water use patterns and peaks reported by others and pave the way for further work in this field.

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A. Appendix A

Extra 15-minute interval periods

Table A.1: Extra 15-minute period recordings for houses H02 and H04

House H02		House H04		
27/10/2012 10:45	30/08/2014 10:45	16/10/2012 10:15	28/03/2014 10:15	26/05/2015 10:15
27/10/2012 10:45	26/09/2014 10:45	08/11/2012 10:15	19/04/2014 10:15	20/06/2015 10:15
22/11/2012 10:45	18/11/2014 10:45	03/12/2012 10:15	16/05/2014 10:15	12/07/2015 10:15
19/12/2012 10:45	13/12/2014 10:45	18/01/2013 10:15	07/06/2014 10:15	06/08/2015 10:15
15/01/2013 10:45	10/01/2015 10:45	11/02/2013 10:15	02/07/2014 10:15	29/08/2015 10:15
08/03/2013 10:45	02/03/2015 10:45	08/03/2013 10:15	25/07/2014 10:15	20/09/2015 10:15
03/04/2013 10:45	29/03/2015 10:45	01/04/2013 10:15	16/08/2014 10:15	15/10/2015 10:15
30/04/2013 10:45	26/04/2015 10:45	17/05/2013 10:15	10/09/2014 10:15	07/11/2015 10:15
27/05/2013 10:45	24/05/2015 10:45	05/07/2013 10:15	04/10/2014 10:15	29/11/2015 10:15
19/07/2013 10:45	21/06/2015 10:45	29/07/2013 10:15	28/10/2014 10:15	24/12/2015 10:15
16/08/2013 10:45	19/07/2015 10:45	23/08/2013 10:15	21/11/2014 10:15	16/01/2016 10:15
13/09/2013 10:45	11/09/2015 10:45	11/10/2013 10:15	13/12/2014 10:15	08/02/2016 10:15
11/10/2013 10:45	08/10/2015 10:45	05/11/2013 10:15	07/01/2015 10:15	
07/11/2013 10:45	29/11/2015 10:45	15/01/2014 10:15	30/01/2015 10:15	
03/12/2013 10:45	27/12/2015 10:45	08/02/2014 10:15	22/02/2015 10:15	
30/01/2014 10:45		06/03/2014 10:15	03/05/2015 10:15	

Table A.2: Extra 15-minute period recordings for houses H06, H07 and H08

House H06			House H07	House H08
13/10/2012 09:45	04/04/2014 09:45	11/04/2015 09:45	14/12/2012 11:15	15/11/2012 10:30
04/11/2012 09:45	25/04/2014 09:45	23/08/2015 09:45	11/08/2013 10:15	31/12/2012 10:30
17/12/2012 09:45	10/06/2014 09:45	16/09/2015 09:45	03/09/2013 10:15	28/01/2013 10:30
05/04/2013 09:45	03/07/2014 09:45	07/10/2015 09:45	25/09/2013 10:15	20/02/2013 10:30
29/04/2013 09:45	24/07/2014 09:45	29/10/2015 09:45	22/12/2013 10:15	16/03/2013 10:30
21/05/2013 09:45	15/08/2014 09:45	19/11/2015 09:45	04/11/2014 10:15	10/04/2013 10:30
12/06/2013 09:45	05/09/2014 09:45	11/12/2015 09:45	09/01/2015 10:15	03/05/2013 10:30
09/09/2013 09:45	27/09/2014 09:45	02/01/2016 09:45	20/02/2015 10:15	11/07/2013 10:30
01/10/2013 09:45	10/11/2014 09:45	24/01/2016 09:45	14/03/2015 10:15	03/08/2013 10:30
23/01/2014 09:45	23/12/2014 09:45	14/02/2016 09:45	17/05/2015 10:15	
14/02/2014 09:45	14/01/2015 09:45		29/06/2015 10:15	
08/03/2014 09:45	05/02/2015 09:45		30/11/2015 10:15	

Table A.3: Extra 15-minute period recordings for houses H09, H12 and H13

House H09		House H12	House H13
18/10/2012 11:00	12/10/2013 11:00	14/02/2013 09:15	05/01/2013 09:45
08/11/2012 11:00	03/11/2013 11:00	03/04/2013 09:15	10/05/2013 09:45
01/12/2012 11:00	25/11/2013 11:00	08/06/2013 09:15	30/06/2013 09:45
23/12/2012 11:00	16/12/2013 11:00	17/04/2014 09:15	26/07/2013 09:45
15/01/2013 11:00	07/01/2014 11:00	09/05/2014 09:15	20/01/2014 09:45
06/02/2013 11:00	30/01/2014 11:00	21/06/2014 09:15	10/03/2014 09:45
28/02/2013 11:00	22/02/2014 11:00		03/04/2014 09:45
22/03/2013 11:00	17/03/2014 11:00		26/04/2014 09:45
12/04/2013 11:00	08/04/2014 11:00		23/05/2014 09:45
05/05/2013 11:00	30/04/2014 11:00		
28/05/2013 11:00	21/05/2014 11:00		
20/06/2013 11:00	13/06/2014 11:00		
12/07/2013 11:00	28/07/2014 11:00		
05/08/2013 11:00	18/08/2014 11:00		
28/08/2013 11:00	09/09/2014 11:00		
20/09/2013 11:00	01/10/2014 11:00		

Table A.4: First part of the extra 15-minute period recordings for house H14

House H14				
30/12/2013 01:00	30/12/2013 07:45	30/12/2013 14:45	30/12/2013 21:45	31/12/2013 06:15
30/12/2013 01:30	30/12/2013 08:00	30/12/2013 15:00	30/12/2013 22:00	31/12/2013 06:30
30/12/2013 02:00	30/12/2013 08:15	30/12/2013 15:45	30/12/2013 22:15	31/12/2013 06:45
30/12/2013 02:15	30/12/2013 08:30	30/12/2013 16:00	30/12/2013 22:30	31/12/2013 07:00
30/12/2013 02:30	30/12/2013 08:45	30/12/2013 16:15	30/12/2013 23:00	31/12/2013 07:15
30/12/2013 02:45	30/12/2013 09:00	30/12/2013 16:30	30/12/2013 23:30	31/12/2013 07:30
30/12/2013 03:00	30/12/2013 09:15	30/12/2013 16:45	30/12/2013 23:45	31/12/2013 07:45
30/12/2013 03:15	30/12/2013 09:30	30/12/2013 17:00	31/12/2013 00:00	31/12/2013 08:00
30/12/2013 03:30	30/12/2013 09:45	30/12/2013 17:15	31/12/2013 00:30	31/12/2013 08:15
30/12/2013 03:45	30/12/2013 10:00	30/12/2013 17:30	31/12/2013 00:45	31/12/2013 08:30
30/12/2013 04:00	30/12/2013 10:30	30/12/2013 17:45	31/12/2013 01:00	31/12/2013 08:45
30/12/2013 04:15	30/12/2013 10:45	30/12/2013 18:00	31/12/2013 01:15	31/12/2013 09:00
30/12/2013 04:30	30/12/2013 11:00	30/12/2013 18:15	31/12/2013 01:30	31/12/2013 09:30
30/12/2013 04:45	30/12/2013 11:15	30/12/2013 18:30	31/12/2013 02:00	31/12/2013 09:45
30/12/2013 05:00	30/12/2013 11:30	30/12/2013 18:45	31/12/2013 02:15	31/12/2013 10:00
30/12/2013 05:15	30/12/2013 11:45	30/12/2013 19:00	31/12/2013 02:30	31/12/2013 10:15
30/12/2013 05:30	30/12/2013 12:00	30/12/2013 19:15	31/12/2013 02:45	31/12/2013 10:30
30/12/2013 05:45	30/12/2013 12:15	30/12/2013 19:30	31/12/2013 03:30	31/12/2013 10:45
30/12/2013 06:00	30/12/2013 12:30	30/12/2013 19:45	31/12/2013 03:45	31/12/2013 11:00
30/12/2013 06:15	30/12/2013 12:45	30/12/2013 20:00	31/12/2013 04:30	31/12/2013 11:15
30/12/2013 06:30	30/12/2013 13:00	30/12/2013 20:15	31/12/2013 04:45	31/12/2013 12:30
30/12/2013 06:45	30/12/2013 13:15	30/12/2013 20:30	31/12/2013 05:00	31/12/2013 12:30
30/12/2013 07:00	30/12/2013 13:30	30/12/2013 20:45	31/12/2013 05:15	31/12/2013 12:45
30/12/2013 07:15	30/12/2013 14:00	30/12/2013 21:00	31/12/2013 05:45	31/12/2013 13:00
30/12/2013 07:30	30/12/2013 14:30	30/12/2013 21:15	31/12/2013 06:00	

Table A.5: Second part of the extra 15-minute period recordings for house H14

House H14				
31/12/2013 13:15	31/12/2013 22:30	30/12/2014 10:00	30/12/2014 23:30	31/12/2014 13:30
31/12/2013 13:30	31/12/2013 22:45	30/12/2014 10:30	31/12/2014 00:15	31/12/2014 14:30
31/12/2013 13:45	31/12/2013 23:00	30/12/2014 11:00	31/12/2014 00:45	31/12/2014 15:15
31/12/2013 14:00	31/12/2013 23:15	30/12/2014 11:15	31/12/2014 01:00	31/12/2014 15:45
31/12/2013 14:15	01/01/2014 14:47	30/12/2014 12:30	31/12/2014 01:45	31/12/2014 16:30
31/12/2013 14:30	30/12/2014 00:30	30/12/2014 12:45	31/12/2014 03:00	31/12/2014 16:45
31/12/2013 14:30	30/12/2014 00:45	30/12/2014 13:15	31/12/2014 03:45	31/12/2014 17:00
31/12/2013 14:45	30/12/2014 01:00	30/12/2014 13:30	31/12/2014 04:30	31/12/2014 17:15
31/12/2013 15:30	30/12/2014 01:15	30/12/2014 13:45	31/12/2014 05:15	31/12/2014 17:45
31/12/2013 15:45	30/12/2014 01:45	30/12/2014 14:00	31/12/2014 05:30	31/12/2014 18:00
31/12/2013 16:00	30/12/2014 02:30	30/12/2014 14:30	31/12/2014 05:45	31/12/2014 18:15
31/12/2013 16:15	30/12/2014 02:45	30/12/2014 14:45	31/12/2014 06:00	31/12/2014 18:45
31/12/2013 16:30	30/12/2014 03:00	30/12/2014 02:00	31/12/2014 06:15	31/12/2014 19:00
31/12/2013 17:45	30/12/2014 03:15	30/12/2014 15:30	31/12/2014 06:30	31/12/2014 19:15
31/12/2013 18:30	30/12/2014 03:45	30/12/2014 16:00	31/12/2014 06:45	31/12/2014 19:30
31/12/2013 18:45	30/12/2014 04:15	30/12/2014 16:15	31/12/2014 07:00	31/12/2014 19:45
31/12/2013 19:00	30/12/2014 04:30	30/12/2014 18:15	31/12/2014 07:15	
31/12/2013 19:15	30/12/2014 05:15	30/12/2014 18:45	31/12/2014 07:30	
31/12/2013 19:45	30/12/2014 05:30	30/12/2014 19:00	31/12/2014 09:15	
31/12/2013 20:00	30/12/2014 06:15	30/12/2014 20:00	31/12/2014 09:30	
31/12/2013 21:15	30/12/2014 07:30	30/12/2014 20:15	31/12/2014 09:45	
31/12/2013 21:30	30/12/2014 07:45	30/12/2014 20:45	31/12/2014 10:00	
31/12/2013 21:45	30/12/2014 08:15	30/12/2014 21:15	31/12/2014 10:15	
31/12/2013 22:00	30/12/2014 08:45	30/12/2014 22:45	31/12/2014 11:00	
31/12/2013 22:15	30/12/2014 09:45	30/12/2014 23:00	31/12/2014 12:15	

Table A.6: Extra 15-minute period recordings for houses H19 and H21

House H19	House H21
20/11/2012 10:00	12/01/2013 10:45
12/12/2012 10:00	
01/01/2013 10:00	
06/03/2013 09:45	
06/03/2013 10:00	
25/03/2013 10:00	
17/04/2013 10:00	
09/05/2013 10:00	
01/06/2013 10:00	
25/06/2013 10:00	

B. Appendix B

Missing 15-minute intervals

Table B.1: Missing 15-minute period recordings for houses H02, H03 and H04

House H02	No of intervals	House H02	No of intervals	House H03	No of intervals	House H04	No of intervals
01/01/2013 00:00	2	23/10/2015 03:00	1	01/01/2013 00:00	2	01/01/2013 00:00	2
01/01/2013 00:15	2	23/10/2015 03:30	1	01/01/2013 00:15	2	01/01/2013 00:15	2
01/01/2014 00:00	2	23/10/2015 05:00	1	01/01/2014 00:00	2	01/01/2014 00:00	2
01/01/2014 00:15	2	23/10/2015 05:30	1	01/01/2014 00:15	2	01/01/2014 00:15	2
22/10/2015 20:45	1	23/10/2015 06:00	1	01/01/2015 00:00	2	01/01/2015 00:00	2
22/10/2015 21:15	1	23/10/2015 06:15	1	01/01/2015 00:15	2	01/01/2015 00:15	2
22/10/2015 21:45	1	23/10/2015 06:30	1	01/01/2016 00:00	2	01/01/2016 00:00	2
22/10/2015 22:15	1	23/10/2015 07:00	1	01/01/2016 00:15	2	01/01/2016 00:15	2
22/10/2015 22:45	1	23/10/2015 07:15	1				
22/10/2015 23:00	1	23/10/2015 08:30	1				
22/10/2015 23:45	1	01/01/2016 00:00	2				
23/10/2015 01:30	1	01/01/2016 00:15	2				
23/10/2015 02:15	1						

Table B.2: Missing 15-minute period recordings for houses H05, H06 and H08

House H05	No of intervals	House H06	No of intervals	House H07	No of intervals	House H08	No of intervals
01/01/2013 00:00	2	01/01/2013 00:00	2	01/01/2013 00:00	2	01/01/2013 00:00	2
01/01/2013 00:15	2	01/01/2013 00:15	2	01/01/2013 00:15	2	01/01/2013 00:15	2
01/01/2014 00:00	2	01/01/2014 00:00	2	01/01/2014 00:00	2	01/01/2014 00:00	2
01/01/2014 00:15	2	01/01/2014 00:15	2	01/01/2014 00:15	2	01/01/2014 00:15	2
30/11/2014 11:15	1	01/01/2015 00:00	2	07/03/2014 14:30	2		
01/01/2015 00:00	2	01/01/2015 00:15	2	07/03/2014 14:45	2		
01/01/2015 00:15	2	01/01/2016 00:00	2	01/01/2016 00:00	2		
		01/01/2016 00:15	2	01/01/2016 00:15	2		

Table B.3: Missing 15-minute period recordings for houses H09, H13 and H14

House H09	No of intervals	House H12	No of intervals	House H13	No of intervals	House H14	No of intervals
01/01/2013 00:00	2	01/01/2013 00:00	2	01/01/2013 00:00	2	01/01/2013 00:00	2
01/01/2013 00:15	2	01/01/2013 00:15	2	01/01/2013 00:15	2	01/01/2013 00:15	2
01/01/2014 00:00	2	01/01/2014 00:00	2	01/01/2014 00:00	2		
01/01/2014 00:15	2	01/01/2014 00:15	2	01/01/2014 00:15	2		
		01/01/2015 00:00	2				
		01/01/2015 00:15	2				

Table B.4: Missing 15-minute period recordings for houses H19, H20 and H21

House H19	No of intervals	House H20	No of intervals	House H21	No of intervals
01/01/2013 00:00	2	01/01/2013 00:00	2	01/01/2013 00:00	2
01/01/2013 00:15	2	01/01/2013 00:15	2	01/01/2013 00:15	2
06/03/2013 10:00	1	01/01/2014 00:00	2	12/01/2013 11:00	1
06/03/2013 10:15	1	01/01/2014 00:15	2		
		01/01/2015 00:00	2		
		01/01/2015 00:15	2		

C. Appendix C

Longer missing periods of data

Table C.1: Longer missing periods for houses H07, H10, H14 and H19

House H07	House H10	House H14	House H19
30/07/2014 14:30	11/01/2013 10:15	04/09/2013 09:45	11/01/2013 10:00
04/08/2014 08:45	12/01/2013 01:45	07/09/2013 20:00	11/01/2013 20:45
12/09/2014 15:00		25/09/2013 10:15	
23/09/2014 10:15		01/10/2013 06:16	
20/08/2015 16:00			
19/10/2015 15:30			

D. Appendix D

15-minute PFs for developed patterns

Table D.1: 15-minute PFs for the average diurnal pattern

Hour of day	$PF_{15\text{-}min}$	Hour of day	$PF_{15\text{-}min}$	Hour of day	$PF_{15\text{-}min}$	Hour of day	$PF_{15\text{-}min}$
00:00	0.298	06:00	0.559	12:00	1.229	18:00	1.447
00:15	0.235	06:15	0.801	12:15	1.112	18:15	1.513
00:30	0.231	06:30	1.211	12:30	1.187	18:30	1.646
00:45	0.190	06:45	1.551	12:45	1.001	18:45	1.461
01:00	0.142	07:00	1.772	13:00	1.032	19:00	1.399
01:15	0.129	07:15	2.236	13:15	1.025	19:15	1.669
01:30	0.170	07:30	2.345	13:30	0.979	19:30	1.691
01:45	0.141	07:45	2.174	13:45	1.042	19:45	1.618
02:00	0.126	08:00	2.035	14:00	0.858	20:00	1.672
02:15	0.133	08:15	1.853	14:15	0.846	20:15	1.516
02:30	0.145	08:30	1.930	14:30	0.938	20:30	1.540
02:45	0.114	08:45	1.774	14:45	0.792	20:45	1.508
03:00	0.152	09:00	1.860	15:00	0.900	21:00	1.440
03:15	0.121	09:15	1.669	15:15	0.884	21:15	1.319
03:30	0.123	09:30	1.666	15:30	0.920	21:30	1.229
03:45	0.154	09:45	1.665	15:45	0.944	21:45	1.098
04:00	0.115	10:00	1.629	16:00	0.943	22:00	0.968
04:15	0.112	10:15	1.609	16:15	0.924	22:15	0.806
04:30	0.132	10:30	1.506	16:30	0.933	22:30	0.776
04:45	0.120	10:45	1.507	16:45	0.992	22:45	0.650
05:00	0.114	11:00	1.403	17:00	1.202	23:00	0.572
05:15	0.170	11:15	1.347	17:15	1.249	23:15	0.523
05:30	0.248	11:30	1.251	17:30	1.281	23:30	0.432
05:45	0.300	11:45	1.202	17:45	1.503	23:45	0.321

Table D.2: 15-minute PFs for the average weekday pattern

Hour of day	$PF_{15\text{-min}}$	Hour of day	$PF_{15\text{-min}}$	Hour of day	$PF_{15\text{-min}}$	Hour of day	$PF_{15\text{-min}}$
00:00	0.266	06:00	0.700	12:00	1.028	18:00	1.613
00:15	0.182	06:15	0.960	12:15	0.877	18:15	1.705
00:30	0.200	06:30	1.486	12:30	0.951	18:30	1.895
00:45	0.125	06:45	1.909	12:45	0.769	18:45	1.609
01:00	0.101	07:00	2.226	13:00	0.837	19:00	1.519
01:15	0.090	07:15	2.791	13:15	0.812	19:15	1.866
01:30	0.138	07:30	2.836	13:30	0.748	19:30	1.973
01:45	0.101	07:45	2.485	13:45	0.857	19:45	1.860
02:00	0.090	08:00	2.135	14:00	0.702	20:00	1.925
02:15	0.127	08:15	1.859	14:15	0.699	20:15	1.730
02:30	0.134	08:30	1.815	14:30	0.757	20:30	1.772
02:45	0.098	08:45	1.465	14:45	0.663	20:45	1.725
03:00	0.130	09:00	1.506	15:00	0.755	21:00	1.661
03:15	0.086	09:15	1.303	15:15	0.845	21:15	1.560
03:30	0.095	09:30	1.338	15:30	0.833	21:30	1.375
03:45	0.143	09:45	1.358	15:45	0.934	21:45	1.221
04:00	0.095	10:00	1.302	16:00	0.900	22:00	1.089
04:15	0.105	10:15	1.346	16:15	0.864	22:15	0.879
04:30	0.122	10:30	1.185	16:30	0.964	22:30	0.869
04:45	0.107	10:45	1.221	16:45	1.052	22:45	0.688
05:00	0.096	11:00	1.140	17:00	1.318	23:00	0.602
05:15	0.156	11:15	1.116	17:15	1.372	23:15	0.551
05:30	0.253	11:30	0.943	17:30	1.474	23:30	0.421
05:45	0.342	11:45	1.003	17:45	1.734	23:45	0.340

Table D.3: 15-minute PFs for the average weekend pattern

Hour of day	$PF_{15\text{-}min}$	Hour of day	$PF_{15\text{-}min}$	Hour of day	$PF_{15\text{-}min}$	Hour of day	$PF_{15\text{-}min}$
00:00	0.365	06:00	0.263	12:00	1.654	18:00	1.095
00:15	0.347	06:15	0.466	12:15	1.610	18:15	1.105
00:30	0.298	06:30	0.629	12:30	1.687	18:30	1.118
00:45	0.328	06:45	0.792	12:45	1.493	18:45	1.147
01:00	0.232	07:00	0.809	13:00	1.446	19:00	1.145
01:15	0.212	07:15	1.059	13:15	1.478	19:15	1.251
01:30	0.239	07:30	1.302	13:30	1.468	19:30	1.094
01:45	0.226	07:45	1.512	13:45	1.436	19:45	1.106
02:00	0.202	08:00	1.820	14:00	1.190	20:00	1.136
02:15	0.146	08:15	1.840	14:15	1.158	20:15	1.061
02:30	0.171	08:30	2.172	14:30	1.323	20:30	1.048
02:45	0.151	08:45	2.428	14:45	1.064	20:45	1.048
03:00	0.199	09:00	2.609	15:00	1.210	21:00	0.973
03:15	0.198	09:15	2.441	15:15	0.965	21:15	0.810
03:30	0.184	09:30	2.357	15:30	1.106	21:30	0.920
03:45	0.178	09:45	2.312	15:45	0.965	21:45	0.839
04:00	0.158	10:00	2.318	16:00	1.034	22:00	0.712
04:15	0.129	10:15	2.166	16:15	1.053	22:15	0.652
04:30	0.154	10:30	2.185	16:30	0.866	22:30	0.580
04:45	0.148	10:45	2.112	16:45	0.865	22:45	0.570
05:00	0.152	11:00	1.958	17:00	0.958	23:00	0.509
05:15	0.200	11:15	1.836	17:15	0.989	23:15	0.464
05:30	0.237	11:30	1.902	17:30	0.870	23:30	0.457
05:45	0.211	11:45	1.624	17:45	1.014	23:45	0.280

E. Appendix E

Calculation values of PFs

Table E.1: Maximum and average values obtained for the calculation of 15-minute PFs

Number	House number	Year	Maximum value (ℓ/s)	Average value (ℓ/s)	$PF_{15\text{-min}}$
1	H02	2013	0.4425	0.002	202.7
1	H02	2014	0.2304	0.001	185.1
1	H02	2015	0.2503	0.001	201.0
2	H03	2013	0.2033	0.002	94.4
2	H03	2014	0.1830	0.002	75.1
2	H03	2015	0.2066	0.002	88.8
3	H04	2013	0.2646	0.002	160.5
3	H04	2014	0.3254	0.002	151.7
3	H04	2015	0.2532	0.001	187.8
4	H05	2013	0.1220	0.002	63.6
4	H05	2014	0.2488	0.004	68.5
5	H06	2013	0.3012	0.011	26.4
6	H07	2013	0.2883	0.003	84.6
6	H07	2014	0.3317	0.003	97.7
6	H07	2015	0.3650	0.004	104.3
7	H09	2013	0.2712	0.002	130.3
8	H12	2013	0.2568	0.003	81.6
8	H12	2014	0.2837	0.003	93.4
9	H13	2013	0.2922	0.002	157.4
10	H14	2013	0.1719	0.003	49.4
10	H14	2014	0.1544	0.003	59.9
10	H14	2015	0.3926	0.002	159.7
11	H20	2013	0.2396	0.002	140.5
11	H20	2014	0.2075	0.001	149.8

Table E.2: Maximum and average values obtained for the calculation of PHFs

Number	House number	Year	Maximum value (ℓ/s)	Average value (ℓ/s)	PHF
1	H02	2013	0.448	0.009	51.3
1	H02	2014	0.270	0.006	46.6
1	H02	2015	0.404	0.005	81.0
2	H03	2013	0.518	0.009	60.1
2	H03	2014	0.295	0.010	30.3
2	H03	2015	0.399	0.009	42.9
3	H04	2013	0.558	0.007	84.6
3	H04	2014	0.548	0.009	63.8
3	H04	2015	0.847	0.005	157.0
4	H05	2013	0.227	0.008	29.5
4	H05	2014	0.254	0.015	17.5
5	H06	2013	0.921	0.046	20.1
6	H07	2013	0.690	0.014	50.7
6	H07	2014	0.583	0.014	43.0
6	H07	2015	0.532	0.014	38.0
7	H09	2013	0.323	0.008	38.8
8	H12	2013	0.487	0.012	40.1
8	H12	2014	0.425	0.011	37.1
9	H13	2013	0.300	0.007	40.5
10	H14	2013	0.337	0.014	24.2
10	H14	2014	0.574	0.010	55.7
10	H14	2015	0.422	0.010	42.9
11	H20	2013	0.308	0.007	45.2
11	H20	2014	0.349	0.006	63.0

Table E.3: Obtained maximum and average values for the calculation of PDFs

Number	House number	Year	Maximum value (ℓ/s)	Average value (ℓ/s)	PDF
1	H02	2013	0.775	0.267	2.9
1	H02	2014	0.573	0.139	4.1
1	H02	2015	0.760	0.120	6.4
2	H03	2013	1.372	0.207	6.6
2	H03	2014	1.207	0.234	5.2
2	H03	2015	1.227	0.223	5.5
3	H04	2013	1.515	0.158	9.6
3	H04	2014	2.131	0.206	10.4
3	H04	2015	1.921	0.129	14.9
4	H05	2013	1.028	0.348	3.0
4	H05	2014	0.868	0.300	2.9
5	H06	2013	9.380	1.098	8.6
6	H07	2013	1.246	0.326	3.8
6	H07	2014	1.665	0.327	5.1
6	H07	2015	1.343	0.336	4.0
7	H09	2013	0.877	0.200	4.4
8	H12	2013	1.964	0.292	6.7
8	H12	2014	1.163	0.275	4.2
9	H13	2013	0.472	0.178	2.7
10	H14	2013	2.316	0.334	6.9
10	H14	2014	3.157	0.247	12.8
10	H14	2015	0.603	0.236	2.6
11	H20	2013	1.305	0.164	8.0
11	H20	2014	1.401	0.133	10.5